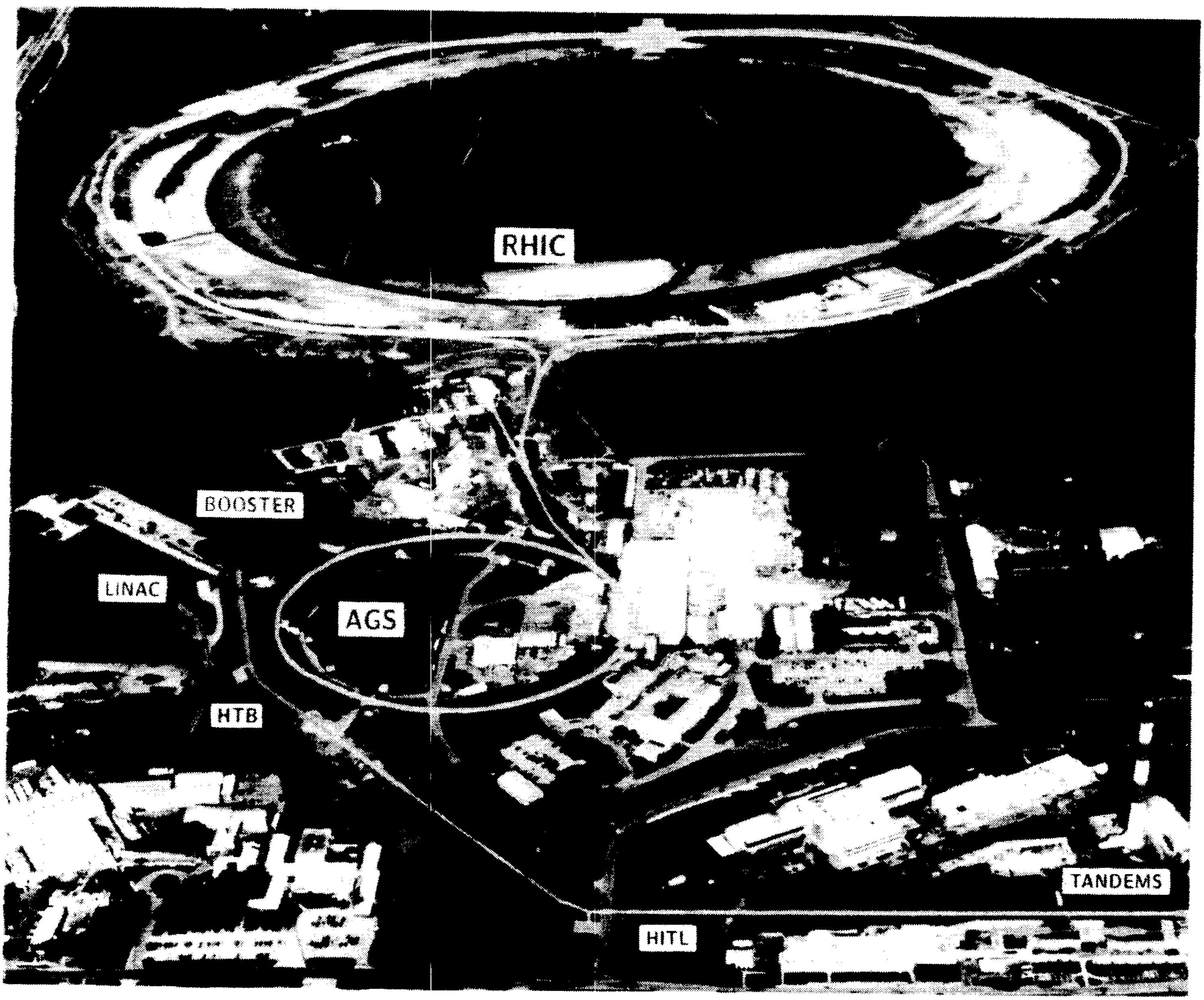
Safety Analysis Report for the HITL-to-Booster (HTB) Heavy Ion Beamline



BROOKHAVEN NATIONAL LABORATORY

MEMORANDUM

DATE: October 1, 1991

TO: P. Bond, D. Lowenstein

FROM: G. C. Kinne G C Kinne

SUBJECT: **Approval of HITL Safety Analysis Report (SAR)**

In accord with the recommendations of the Laboratory Environment, Safety and Health (ES&H) Committee, the HITL Safety Analysis Report is approved subject to the Committee's satisfaction of the following:

a. Determination of where the floor drain sump discharges to.

b. Include building numbers of exit locations on the figures.

c. Determine if the operation of the smoke exhaust system should be an Operational Safety Limit (OSL).

d. Label Operational Safety Limits by a unique numbering system.

e. Verify that each OSL is covered in the Tandem operators' training and that there is a corresponding procedure.

f. Incorporate other minor typos and comments discussed at the meeting.

cc: R. Casey
S. Hoey
B. Medaris
T. Robinson

BROOKHAVEN NATIONAL LABORATORY

MEMORANDUM

DATE: September 27, 1991

TO: T. Robinson

FROM: J. Levesque J.L.

SUBJECT: **Fire Protection Related Operational Safety Limit**

This memo will confirm our joint agreements on the Operational Safety Limits (OSL) related to the fire protection in HTB.

There is no OSL related to fire protection for the HTB. This is based on the lack of any potential consequences exceeding DOE limits on property damage, programmatic interruption, or threat to personnel.

To document this process, for this and future projects, the Fire Protection Engineering Group has "Drafted" the attached Guide. Our hope is that it will become BNL's policy as part of a SAR developmental process.

JL/sc
attachment
cc: W. R. Casey
J. Deitz
S. Hoey (Secy. ES&H Com)
B. Medaris (Chair ES&H Com)
f: P.1.2.2
SafeLimi.Gud
1.2

BROOKHAVEN NATIONAL LABORATORY

MEMORANDUM

DATE: October 3, 1991

TO: M. O'Brien, H. Schulman

FROM: C. Carlson C Carlson

SUBJECT: HITL/HTB Fault Studies Training

Please find attached a list of TVDG operators who have been trained in the HITL/HTB Beam Fault Radiation Measurement Procedure.

This procedure includes the HITL/HTB OSL's and should be considered as satisfaction of documented training in this area.

CC/sa

cc: T. Robinson
E. Lessard

attach.

The following TVDG personnel have been trained in the HITL/HTB Beam Fault Radiation Measurement Procedure, including the deviations from usual TVDG safety procedures, and are qualified to participate in the setup and operation of the TVDG for the procedure.

JIM WIDGREN Jim Widgren 10/2/91

Alan Gustavsson Alan Gustavsson 10/2/91

Hans Abendroth Hans Abendroth 10/2/91

George Westwater George Westwater 10/2/91

Michael Wiplich Michael Wiplich 10/2/91

David A Graham DAVID A GRAHAM 10/3/91

Michael Morello Michael Morello 10/3/91

Charles W. Carlson 10/3/91

TVDG Operations Supervisor Signature/date

BROOKHAVEN NATIONAL LABORATORY

MEMORANDUM

DATE: September 26, 1991

TO: T. Robinson

FROM: G. Schroeder

SUBJECT: NESHAPs Compliance Review of the Heavy Ion Beamline

As required by the Clean Air Act, the use of the HIB as outlined in your memos of August 7th and September 19, 1991 to R. Miltenberger and M. O'Brien, respectively, has been evaluated for compliance with air emission standards as outlined in 40 CFR 61 Subpart H. The dosimetric impact to the closest off-site resident is substantially lower than the administrative level (0.1 mrem per year) for formal submission to the EPA for a NESHAPs permit to construct/operate the facility. The attached evaluation is your record that the assessment was performed by the S&EP Division. It should be maintained in your records as a compliance document. Should you alter the operating conditions of the facility such that it might affect the radionuclide output estimated within the evaluation, the conclusions drawn will need to be reassessed.

BLC
Attachment

cc: W. Casey w/o attachment
M. Davis w/o attachment
R. Miltenberger w/attachment
C. Polanish, DOE w/attachment

SAFETY ANALYSIS REPORT

for the

HITL-to-BOOSTER (HTB)

HEAVY ION BEAMLINE

Author	Theodore G. Robinson	Date
TVDG Group Leader	Peter Thieberger	11/21/91 Date
Department Chairman	Peter D. Bond	10/17/91 Date
S&EP Division Head	William R. Casey	11/18/91 Date

Final; October 7, 1991

TABLE OF CONTENTS

0.0 EXECUTIVE SUMMARY

In this document the HITL to Booster (HTB) beamline complex is described and evaluated for compliance with codes, laws, standards and regulations including those of Brookhaven National Laboratory as well as applicable Federal and State Agencies. The operation, training of personnel and administration of the facility is also described.

Hazards are identified, described, assessed and where necessary mitigated to result in a facility that is as safe as practical. Only two hazards are identified as requiring detailed review, those being fire and radiation.

In the case of fire, good engineering practices as well as the inclusion of appropriate fire detection and suppression systems result in a risk level classification of Low Risk.

Radiation levels encountered during normal operation are extremely low, to the point of being often difficult to measure. During conceivable fault conditions the levels are still orders of magnitude lower than those encountered at high energy accelerators or reactors. Even these low radiation levels found within the complex are further reduced through hardware limitations and administrative procedures. Appropriate Operational Safety Limits are imposed on critical systems to further reduce risk of unnecessary exposure. The risk level assigned to radiation concerns is thus Low Risk.

The risk assessment process, coupled with confidence gained through more than five years of operation with a functionally identical transport line, results in the overall categorization of the HTB facility as Low Risk.

1.0 INTRODUCTION AND PURPOSE

A unique accelerator complex capable of providing beams for heavy ion research in the energy range up to 14.6 GeV/nucleon has been built at BNL. The facility consists of linking two machines, the Alternating Gradient Synchrotron (AGS) and the coupled Tandems, both of which have been operating successfully for many years. The fine emittance and energy resolution of beams from the Tandems permit direct injection of the lighter heavy ions into the AGS.

The existing Heavy Ion Transfer Line (HITL) serves as a link for the transport and injection of intermediate mass ions (up to the mass of sulfur) directly to AGS. The limitation to lighter masses is imposed by the level of AGS vacuum, which demands that ions be fully stripped of electrons prior to injection. Only ions of mass 32 or less can be produced in usable intensities and also be fully stripped at Tandem energies. After AGS injection, the ions are accelerated to an energy of 14.6 GeV/nucleon and then extracted to the AGS experimental areas for fixed target physics research. The operation of HITL is a straightforward extension of Tandem operations and the safety considerations are a subset of those encountered at the Tandem. Proper coordination between AGS and Tandem during periods of joint operation are well developed.

This document addresses the construction of an extension of the HITL beam line, called HTB (HITL-to-Booster). The HTB tunnel will serve to extend the transport of heavy ions from the Tandem to the Booster. Because of the excellent vacuum levels in the Booster, partially stripped ions heavier than sulfur can be accelerated to intermediate energies and then fully stripped prior to AGS injection. After final acceleration to 14.6 GeV/nucleon in the AGS, heavy ion projectiles throughout the periodic table may be utilized in fixed target experiments in the AGS experimental area. The ES&H considerations for HTB are not significantly different from those in the existing HITL.

At a future time, in conjunction with the Relativistic Heavy Ion Collider (RHIC) project, the HITL/HTB line will deliver heavy ions from the Tandem to the Booster for injection into the AGS and ultimately to RHIC for colliding beam physics. This future RHIC scenario is not reviewed in this report.

2.0 DESCRIPTION OF FACILITY

2.1 SITE

The HTB and associated structures have a developed length of approximately 800 feet in addition to the nominal 1900 feet for the HITL line. The HTB route was determined by existing Tandem Van de Graaff/HITL structures, the injection point into the Booster (C-3 section), the location of existing roads and services, the topography and construction cost considerations. The Laboratory Site Plan is illustrated in Fig. 6.1, while Fig. 6.2 shows the Local Site Plan.

2.2 STRUCTURES

2.2.1 Tunnel

An underground spiral steel tunnel has been installed from the northwestern terminus of the HITL facility to the Booster, a distance of about 800 L.F. The tunnel has a uniform cross section of 10'-0" diameter and is constructed of corrugated steel pipe positioned in open trenches which are then backfilled. A poured-in-place concrete floor 1'-6" thick along the center line acts as a foundation for the beamline and also as a walking surface. This arrangement results in clear height at tunnel centerline of 8'-6". Exits from the tunnel are at the new Power Supply House 941, at the existing HITL Power Supply House #2 (908), and also via a spiral staircase escape shaft near the northern end of the tunnel in the vicinity of the Linac. The relationship of the tunnel and structures to the exits can be seen on Fig. 6.2.

2.2.2 HITL/HTB Junction

The reinforced concrete vault at the northwestern terminus of HITL was expanded to accept the corrugated steel pipe comprising the beginning of HTB. The HTB tunnel begins a pitch downward at this point to accommodate the approximate 10 foot difference in elevation between HITL and the Booster ring. Emergency escape from this area is provided through HITL Power Supply House #2 (908) immediately adjacent to this area. Refer to Fig. 6.3.

2.2.3 Transition Structure at Mid-point

At the double dipole bend ($13° + 13°$) near the approximate center of HTB, a subterranean reinforced concrete transition section and building foundation receives the steel tunnel from both ends. In addition, the concrete structure provides for increased radiation protection and a means of ingress/egress for personnel. At grade, a steel framed pre-engineered type facility with insulated metal siding on a poured concrete foundation (HTB P.S. Bldg. 941) consisting of two rooms has been built. The electrical equipment room contains associated beamline equipment, controls and interlocks, while the mechanical equipment room houses air handling and power distribution equipment. A fire department Siamese connection for the sprinkler/standpipe system is located at 941; however the Fire Department main response panel is found at Bldg. 907 (HITL P.S. House #1). Road access to Bldg. 941 is from Michelson Street, and is illustrated in Fig. 6.4.

2.2.4 Transition through Linac to Booster

At the northwestern end of the main HTB tunnel, the beamline route requires a crossing of the existing Linac tunnel structure and integral HEBT proton transport line. A 25' long, 24" diameter driven pipe sleeve serves to allow HTB beamline insertion into the Linac tunnel. The void between the beampipe and the sleeve has been filled with sandbags to afford sufficient radiation shielding to separate the facilities. The efficacy of the shielding has been tested during Linac fault studies (see Appendix 7.7). The HTB beampipe, due to its slope, avoids intersection with the HEBT line by being vertically displaced approximately 6" above it at the point of closest approach. The plan view of this geometry can be seen in Fig. 6.5, and the elevation in Fig. 6.7.

Downstream of the Linac tunnel a concrete vault has been constructed to house the beam line for the short distance from the HEBT crossing to the Booster tunnel structure, from which it is separated by another pipe sleeve. This arrangement allows for shielding between the Linac and Booster to reduce possible radiation exposure from either machine (see Fig. 6.7). Personnel and equipment entry into this less than 50 foot long concrete structure is through a portal cut in the Linac tunnel wall.

2.3 SERVICES AND UTILITIES

2.3.1 General

All of the above described structures contain normal lighting systems, power receptacles, deionized water, compressed air, telephones, interphones, and ventilation ductwork. Fire detection, fire protection, emergency lighting and emergency exhaust ventilation have also been provided. Floor drains empty into a sump located at the lowest end of the HTB tunnel. Any water in the sump is then pumped to the sanitary sewer system.

2.3.2 Heating, Ventilation and Air Conditioning

Conventional HVAC services are located in Power Supply Building 941 for maintaining comfort levels and sensitive equipment protection. The air circulated into the tunnel and transition structures, however, is not conditioned for human comfort but tempered adequately to control humidity levels for protection of the beam components. This system provides an air change in the tunnel approximately every hour.

2.3.3 Emergency Ventilation

An emergency exhaust ventilation system has been provided with the capability to effect a complete change of air in the HTB portion of the tunnel every 6-7 minutes. This system is designed to operate on automatic control activated by smoke detectors in the tunnel and/or manual controls located in the HITL P.S. House 1 (Bldg. 907).

2.3.4 Electrical Distribution

Primary power is provided by 480 VAC feeders from the HITL Substation to a distribution panel located within the HITL tunnel near Bldg. 908. Local power is then routed to switchgear in Bldg. 941 for distribution within the HTB tunnel and Linac conjunction area.

2.3.5 Emergency Lighting

Battery-pack emergency light units are strategically located throughout the tunnel and power supply building. They are automatically kept charged and are automatically activated upon loss of normal power.

2.3.6 Water and Air Systems

Deionized water distribution providing magnet and power supply cooling has been extended from the system at the Tandem Van de Graaff Building (901A) that already services HITL.

Compressed air at a nominal 100 psi for operating valves and instruments is supplied from compressors located at the Tandem, and is distributed through the HTB tunnel.

2.3.7 Fire Detection and Protection

Fire and/or smoke detection and protection is accomplished by the installation of various devices and systems as described in detail in Section HTB-4.2.

2.4 BEAM TRANSPORT COMPONENTS

2.4.1 Magnets

The HTB beamline transporting the heavy ions from HITL to the Booster consists of a series of dipole bending, quadrupole focussing, and small horizontal and vertical steerer magnets. Seven quadrupole doublets, one vertical pitching dipole, and two horizontally bending dipoles are located within the primary HTB tunnel. One quadrupole doublet and one vertical pitching dipole are distributed within the HTB tunnel stub structure downstream of the Linac.

The horizontal dipoles require 12 kilowatts each and are water-cooled. The quadrupole doublets are each comprised of two air-cooled singlet lenses mounted on a common base. The quad power consumption is nominally 400 watts per lens; 20 amps at 20 VDC. The two vertical pitching dipoles, one located at either end of HTB, are required to accommodate the 10' elevation change; they are powered from quad supplies and also are rated 20 A at 20 VDC. Eleven pairs of horizontal/vertical steering magnets are found at various locations along the beam path; each steerer magnet is rated 5A at 5 VDC.

The injection bump magnets and the electrostatic inflector used to align and inject the beam onto the Booster beam axis are located within the Booster complex and are not addressed in this SAR.

Appendix 7.1 is a compilation of major devices and their locations.

2.4.2 Power Supplies

The power sources for the above loads are located in the HTB Power Supply House 941. Input voltages to the units are 480 VAC for dipole power supplies and 208 VAC for quadrupole and steerer supplies. DC power to the magnets is distributed via Hypalon (CSPE) jacketed cables contained within cable trays.

The power supplies for the injection bump magnet and inflector are located within the Booster complex, and are not discussed in this document.

2.4.3 Vacuum System

The beamline employs the necessary vacuum components required to achieve and maintain a vacuum of about 10^{-10} Torr. The system consists of roughing pumps, bakeout units, small ion pumps (20 L/sec) located approximately every 70 feet along the beamline, a passive gettering (NEG) strip contained within the vacuum pipe, and the necessary valves and gauges. The activation of the NEG strip, accomplished by means of 208 VAC SCR controllers located throughout the tunnel, takes approximately 24 hours per section to complete and is required only once per several years (depending on ultimate vacuum levels). Procedures for posting and cordoning off areas that become hot during bakeout conditions have been developed and implemented to avoid injury. A fast-acting valve is employed to quickly isolate the HTB and Booster vacuum systems in the unlikely event of a catastrophic vacuum failure.

2.4.4 Beam Instrumentation and Control

Various beam diagnostic devices are strategically located along the beamline (approximately every 140') to measure the optical properties and position of the beam. These include Faraday cups, beam current transformers and beam profile monitors. All necessary controls such as actuators and amplifiers are provided to make these instruments fully remotely operable via computer control.

3.0 OPERATION, TRAINING AND ADMINISTRATION

3.1 OPERATIONS

3.1.1 Beam Transport Operations

The Tandem presently delivers pulsed beams of lighter heavy ions up to the mass of sulfur to the AGS. The description of Tandem operation procedures regarding the generation of these beams is detailed in the HITL FSAR. The increase in mass capability to heavier ions allowed by the Booster imposes no operational restrictions on Tandem procedures, and in fact results in safer conditions due to the reduction of beam-induced radiation levels within HTB.

For ions heavier than sulfur, partially stripped beams can be transported to the Booster for capture at lower harmonics, thus taking advantage of the higher yield for lower charge states. Some representative ions and energies are summarized in the accompanying Table I. Pulsed ion source currents of 80-300 particle microamps are achievable with a nominal duty cycle of 1×10^{-4}. Prior to the insertion of a pulsed beam into HITL/HTB, a DC beam of about the same average intensity can be provided in the transfer line for ease of tuning, all other properties being the same as for the pulsed beam. This DC beam is not available during normal pulsed beam transport however, as a beam chopper employed at the Tandem to improve the pulse risetime precludes transport of DC beams.

Transport through HTB is nominally 100% efficient. For the purpose of a safety analysis one may postulate normal losses of less than 10% at any point, although it will be seen that a 100% loss will be safely dealt with. The beam pulse is inserted into the Booster by the "multi-turn' injection process. The pulse lengths from the Tandem will be varied, depending on species, from 80 μsec to 500 μsec so that 8 beam turns can be injected side by side. The efficiency of the injection process is assumed to be 100%. After injection the Booster rf system captures the beam (with an efficiency of $\approx$70%) and acceleration to full energy proceeds with relatively minor beam losses thereafter.

In terms of radiation sources, these beams produce very much less radiation than that produced by the peak 200 MeV proton beams delivered to the Booster from the Linac. Refer to Table III in Sect. 4.3.2 for representative radiation levels for Tandem-produced heavy ion beams.

Table I. Injection Ions and Energies

Ion	v/c	f (Mhz)	p (GeV/c)	E_{inj} (MeV)	E_{inj} (MeV/n)
C	0.1262	0.5623	1.4211	90.0	7.500
S	0.1000	0.4457	2.9925	150.0	4.688
Cu	0.0782	0.3485	4.5969	180.0	2.857
I	0.0595	0.2653	7.0489	210.0	1.654
Au	0.0478	0.2131	8.7805	210.0	1.066

3.1.2 Tandem/AGS/Booster Operations Interface

The operation of the heavy ion beamlines to the AGS and Booster have physical characteristics which make them a straightforward extension of Tandem experience being operationally very similar to the Target Room beamlines. The control of the whole system may be expected to evolve and possibly be enlarged or consolidated with other tasks as part of a future AGS upgrade or RHIC collider project. Control of the HTB beamline is available from either of two separate locations, the TVDG or AGS control rooms. Beam tuning and equipment control up to the two redundant HTB beam stops located near the Linac tunnel will normally be provided by the Tandem Control Room. Control of these beam stops, and normally the tuning of the beam beyond this point to the Booster will be accomplished by the AGS Main Control Room. Status information and alarms are displayed in both control rooms. Communication links include shared intercom channels, telephones and PA systems.

AGS operating procedures for handling heavy ion beams downstream of the beamstops are covered in Chapter 7 of the AGS Operations Procedures Manual (OPM). Controlled copies of the AGS OPM are maintained in both the AGS and Tandem Control Rooms.

3.1.3 Safety and Operations Responsibilities

During joint Tandem/AGS/Booster operations linkage between the Tandem and AGS operations groups is through the AGS Operations Coordinator and the Tandem Operations Supervisor. They have overall responsibility for all safety matters concerning beamline operation during periods of joint operation. Safety responsibility for the transfer lines and their associated structures rests with the Tandem Operations Supervisor. Beam transport and tuning control prior to the position of the HTB beamstops will normally be accomplished by the Tandem Operations Group, whereas transport downstream of the beamstops is the responsibility of the AGS MCR. The Tandem control room has no access to the HTB beamstop controls, as they are primary radiation protection devices for the Booster and can only be withdrawn upon command from the AGS MCR after satisfaction of all interlock requirements. Since the injection lattice downstream of the beamstops is quite different from that of the HITL/HTB lattice, these mechanisms act as both logical and functional devices to separate the control room functions and responsibilities. In the course of previous joint operations, the AGS Operations Coordinators and operators have been required to become knowledgeable in Tandem beamline related safety procedures. The Tandem Safety Coordinator is responsible for maintenance of all HITL/HTB safety equipment located prior to the HTB beamstops. Safety equipment and interlocks downstream of this point are the responsibility of the AGS Safety Group. The scheduling of operations continues to be carried out by the AGS Scheduling Physicist, and responsibility for implementation of the schedule rests with the AGS Operations Coordinator. Liaison between operating groups is the responsibility of the Tandem and AGS Chiefs of Operations.

3.1.4 Maintenance Responsibilities

During Tandem/AGS/Booster operations and related periods of maintenance and repair, Tandem personnel participate in the weekly AGS scheduling meeting. While there is shared responsibility for maintenance and repair in the HITL/HTB beamlines, most significantly in the area of control systems and instrumentation, it is the Tandem Operations Supervisor's responsibility to identify devices requiring maintenance and to contact the appropriate repair personnel for the portion of the transfer lines preceding the HTB penetration into the Linac vault. Maintenance of equipment located downstream of this point is the responsibility of the AGS/Booster organization. A program is in place for the operations staffs of both groups to facilitate this cooperative mode of operation.

3.1.5 Normal and Emergency Procedures

Both Tandem and AGS groups have well established and documented safety and emergency procedures. The operation of the HTB beamline entails a straightforward extension of operations in these areas, and procedures follow existing standards. The HTB is an extension of the HITL facility and as such all security and fire alarms are wired to the Tandem Control Room with simultaneous notification at the AGS Main Control. The equipment in the primary HTB tunnel will be accessible under existing HITL procedures and supervision. These procedures have recently been upgraded to require key access to the tunnel, with training and sign-off prior to issuance of keys, which is the responsibility of the Tandem Safety Coordinator. Accessibility to equipment in the downstream HTB stub between the Linac and Booster is subject to procedures and supervision lines of responsibility developed at these facilities.

3.2 TRAINING

Training for the Tandem operators, both for accelerator operations and associated beamline transports, is the responsibility of the Tandem Operations Supervisor. All TVDG operators have been trained in the tune and transport of the HITL transfer line, which has been in use successfully for many years. Lines of responsibility for operations and maintenance for the beamline and associated equipment have been established jointly with the AGS Operations Group. Operation of the HTB line is a natural extension of these established lines of responsibility, and as such will be easily integrated into the existing program.

3.3 ADMINISTRATION

The administration lines of responsibility for the Tandem Van de Graaff Facility as pertains to safety issues is as follows:

TVDG FACILITY ES&H RESPONSIBILITIES

The following personnel at the Tandem Van de Graaff Facility are identified as having ES&H responsibilities:

1. TVDG Facility ES&H Coordinators:
   . . . . C. Carlson
   . . . . J. Throwe

2. TVDG Facility ES&H Committee Members:
   . . . . T. Robinson (Chair)
   . . . . J. Benjamin
   . . . . C. Carlson
   . . . . M. Manni
   . . . . J. Throwe
   . . . . F. Zafonte(S&EP ex officio member)

3. ALARA Coordinator . . . . C. Carlson

4. Training Coordinator . . . . C. Carlson

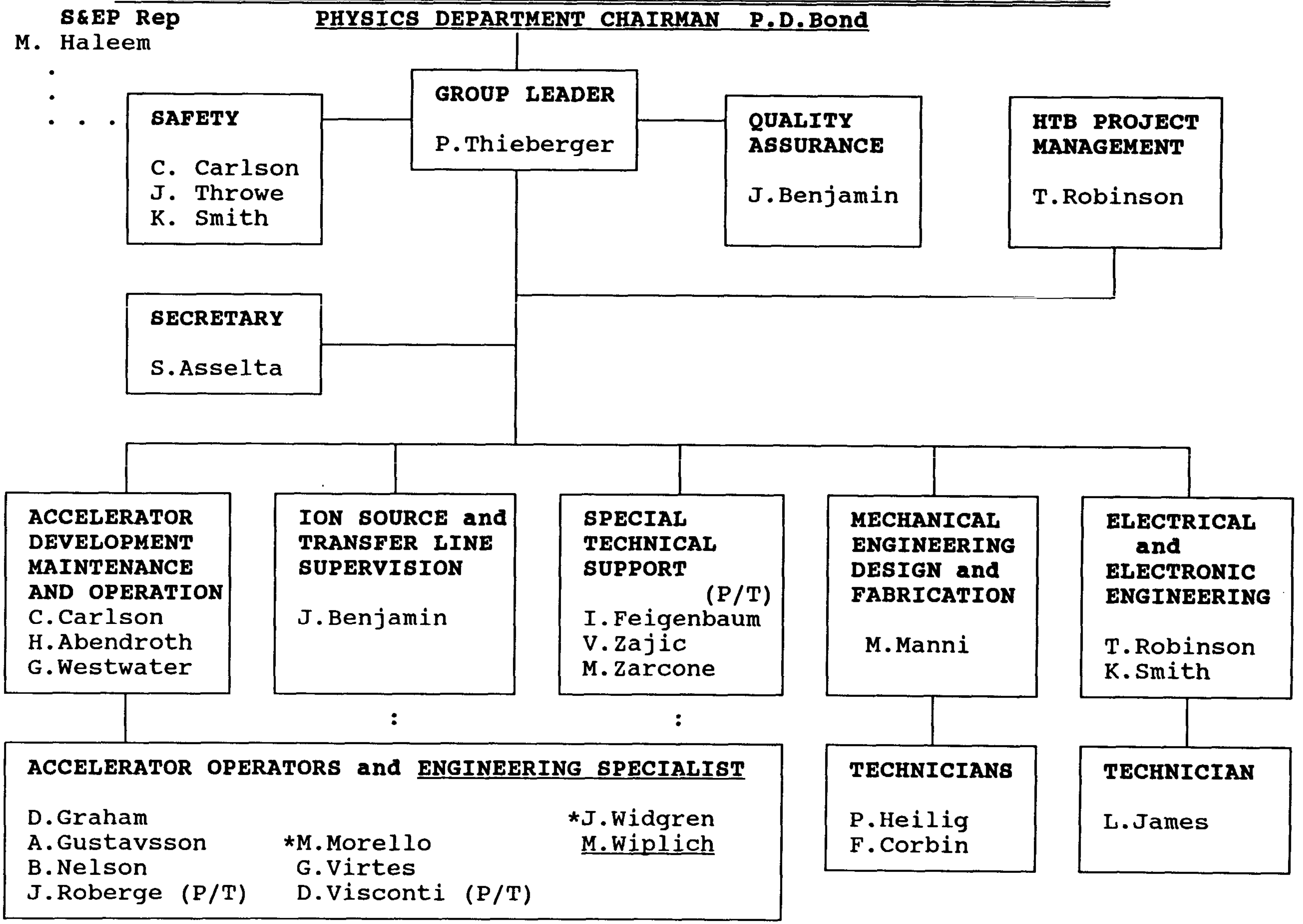
5. Quality Assurance Representative J. Benjamin

6. Local Emergency Coordinator . . C. Carlson

7. Other ES&H special assignments . none

8. S&EP Representatives . . . . S. Haleem
   . . . . F. Zafonte

TANDEM VAN DE GRAAFF OPERATIONS AND DEVELOPMENT GROUP



(* operators in training)

4.0 IDENTIFICATION OF HAZARDS AND SAFEGUARDS

4.1 GENERAL RATIONALE

An analysis of safety, environmental and health factors related to the HTB project leads to the conclusion that only fire, radiation and magnetic field hazards warrant special comment. Hazards related to cryogenic fluids, pressure vessels, toxic materials, asphyxiation, RF fields, and explosive and/or flammable fluids are nonexistent on this project. Hazards related to electrical power, mechanical devices, noise, magnetic fields and air pollution are consistent with similar acceptable hazards existing at both the Tandem Van de Graaff and the AGS. The staffs of both facilities are experienced with these hazards and they continue to minimize the dangers in accordance with present codes, standards and practices. No permanent detrimental impact upon the environment is foreseen as a result of this Project. An S&EP assessment of risk hazards has been completed with regard to NEPA compliance. A copy of the Environmental Evaluation Form and its cover letter are included in Appendix HTB-7.3. In addition, a NESHAPs review has been completed by S&EP. The result of their investigation is that emissions are well below the threshold requiring a NESHAPs permit, and thus the HTB tunnel is in full compliance with the Clean Air Act. Documentation of this determination can be found as Appendix HTB-7.9.

4.2 FIRE

4.2.1 Combustible Loading and Contents Value

As in HITL, the primary combustible loading of the HTB tunnel consists of the magnets, power and control cables and beam diagnostic equipment. None of the materials are highly flammable and, with the possible exception of small amounts of control cable, all are expected to self-extinguish upon the de-energizing of electric power without propagation to other equipment. The total value of 25 magnets within the HTB tunnel downstream of HITL is approximately $150,000 distributed over 800 feet. The highest concentration of equipment within the HTB tunnel is the two horizontal dipoles, two quadrupole doublets, three steerers and three beam instrumentation packages located at the double bend near the midpoint transition area. The aggregate value of the group is $185,000, and it is distributed over 80' of developed tunnel length. It is highly improbable that a fire in any of these components could propagate to other components before the fire would be detected and extinguished. With this assumption, the highest single incident loss would be a dipole with nearby electronics and cabling with a loss of less than $65,000. In addition, sprinklers have been provided for the two dipole locations.

The combustible loading in the equipment house consists of the conventional structural and utility materials plus the building contents of power supplies and control electronics. The value of the HTB P.S. Bldg. 941 with contents is approximately $340,000. A total loss is highly unlikely due to the materials involved and the fire detection provided. The maximum credible loss in the power supply building, the destruction of a single rack of electronics, would not exceed $50,000.

A detailed breakdown of the power supply and instrumentation values can be found as Appendix 7.2.

4.2.2 Safeguards in Power Supply Building 941

Products-of-combustion (P-O-C) detectors and rate-of-rise/fixed temperature detectors have been installed in the power supply building as dictated by the nature of the components and fire loading of the room. There are also manual pull-boxes at the exit. Fire alarms sound locally, at the Tandem and the AGS Control Rooms, and at Police & Fire/Rescue Headquarters. Portable fire extinguishers are also mounted within the power supply building.

4.2.3 Safeguards in the Tunnel Structures

Fire/smoke detection and suppression is consistent with the intent of the National Fire Codes and applicable sections of the BNL Occupational Health and Safety Guide as appropriate for a tunnel structure, with its expected low occupancy, and low fuel loading.

A wet standpipe water main with sprinkler taps at the major dipole locations extends to within 30 feet of the end of the tunnel. Outlet valves and fire hose connections are spaced approximately every 150 feet. The main is fed from HITL P.S. Bldg. #1 (Bldg. 907) near the mid-point of the HITL tunnel. There is a siamese fire department connection outside of Bldg. 941 so that flow through the system may be augmented by a fire department pumper if required.

Fire/Smoke detection has been installed. Sprinklers are installed over beamline component concentrations in the bending magnet area. See Section 4.2.1.

Fire spread to or from the HTB/Linac junction would have to follow a 25' near horizontal installation of insulated beampipe through the 24" diameter pipe that penetrates the earth berm and concrete wall of the Linac. Fire spread by this route is highly unlikely and easily isolated and extinguished. Installation of non-combustible radiation shielding within this penetration (Fig. 6.7) further reduces the likelihood of fire spread between the two facilities.

Over 95% of the power and control cables and wiring in the tunnel have Hypalon jacketing which has low-toxicity, low-smoke, and self-extinguishing ratings. The use of this jacketing will minimize fire propagation and smoke generation in the event of a fire. Polyvinyl Chloride (PVC) and other flammable types of insulation and jacketing have been kept to a minimum.

Portable fire extinguishers are mounted throughout the tunnel.

Joint Tandem/AGS administrative controls are in place to prevent the installation or accumulation of significant amounts of flammable equipment or materials in the HTB tunnel.

4.2.4 Life Safety

Fire alarm bells are located and sized so as to be audible throughout the tunnel and the power supply building complex. The P.A. systems of both the Tandem and the AGS have been extended into the HTB area.

Normal exit from the HTB tunnel is at the Power Supply House (Bldg. 941), or into the HITL tunnel with its previously described exits. There is an emergency exit via a spiral staircase near the northern terminus of the HTB tunnel, near the Linac. The climb from the tunnel floor to grade is approximately 20 feet. The maximum distance from within the tunnel to an exit will be 165 feet. The exit locations can be seen on Drawing HTB-6.2.

Exit widths meet the criteria of the BNL Occupational Health and Safety Guide Section 4.1.2, Para. V-F.

Battery-powered emergency lighting fixtures have been provided at several locations throughout the HTB facility to provide adequate illumination for safe egress in the event of loss of normal lighting. The lighting units are automatically charged and automatically activated upon loss of power.

An emergency air exhaust system has been provided for the tunnel and transition structures. The system is capable of supplying a complete air change every 6-7 minutes. In fire or smoke conditions, this system will be activated automatically by temperature and/or smoke detectors. The system may also be initiated manually at HITL P.S. Bldg. #1 (Bldg. 907) or from the mechanical equipment room of Bldg 941.

4.3 RADIATION

The radiation levels so far experienced in HITL have been determined by the transport of ions in the mass range from carbon to sulfur. At Tandem energies, beam-produced radiation fields tend to decrease with increasing mass, with the worst cases being deuterons and protons. There has been no programmatic reason to transport ions lower in mass than carbon, and the limitation of the highest mass (fully stripped) accepted at AGS was sulfur. The highest anticipated radiation levels were for the carbon beam, and the HITL shielding requirements were designed on this basis. The Booster Design Manual calls for a list of ion masses to be provided by the TVDG ranging from deuterons to gold. The increase in the mass of the accelerated beams from oxygen or silicon to gold will result in a drastic decrease in radiation to less than 0.1 mRem/hr, or essentially undetectable levels; on the other hand the utilization of very low mass particles (i.e. deuterons) will greatly increase radiation levels throughout the entire transport system. The present amount of earth shielding covering HITL and HTB (minimum of 4') is sufficient to adequately shield all radiation resulting from a worst case single-point impact event of all species of maximum energies and masses greater than or equal to carbon.

In recognition of the increased radiation levels associated with low mass beams, as well as the present absence of programs requiring them, Booster management has made a policy commitment that the transport of low mass beams (e.g. less than carbon) which may produce radiation levels exceeding the shielding capabilities provided in both HITL and HTB will not be allowed (ref. OSL-HTB 1.0). In the event that future programs dictate such beams, the shielding requirements and other safety ramifications associated with their transport must be reassessed. Reevaluation of the increased hazards will be done by submission of a revised SAR to the Lab Safety Committee.

4.3.1 The Existing TVDG/HITL Radiation Safety Systems

A full description of the evolvement of the TVDG Radiation Safety System and its extension into the HITL system can be found in the HITL SAR, along with other referenced documents. Since the beam energies, species and average intensities to be transported in the HTB are typical low-hazard Tandem beams, the radiation safety system for the HTB is an extension of the existing Tandem/HITL system.

4.3.2 Measured Radiation Levels

The measured radiation levels documented in the HITL SAR can be considered as worst case scenarios, especially since the emphasis in heavy ion experimentation increasingly calls for heavier ions. Those results show that even for the lowest mass particles to be transported, the radiation levels are 80 mR/hr at 1 meter and 0° from a loss point. Acceleration of the heavier ions results in decreasing radiation levels in the Tandem, HITL and HTB facilities. Production of beams at the Tandem of masses higher than sulfur will yield extremely low radiation levels throughout the transport system to the Booster. The following text and Table III data are reproduced from the HITL SAR.

"The radiation levels produced by beams in this mass-energy regime increase with increasing energy per nucleon, thus the most severe radiation problems are to be expected from the lowest mass that will be accelerated, namely ^{12}C. From the results of Ohnesorge the worst expected neutron dose equivalent rate at 90° from an 8 MeV/A ^{12}C beam of 30 particle microamps and a 1×10^{-4} duty cycle results in an exposure rate of 40 mRem/hr at 1 meter from a total loss point.

Recent measurements of radiation levels from intercepted beams confirm those low anticipated doses. On 2/13/84 various heavy ion beams were accelerated to design energies, then identified according to energy and charge state after being transported around the 90° analyzing magnet. Beam currents were then measured at the image Faraday Cup, then were allowed to impinge on a closed VRC vacuum gate valve after being bent through 50° in the switching magnet. The gate valve is an aluminum plate approximately 3 mm thick. The resultant radiation levels were measured using both the Harwell type FN2/3 Fast Neutron detector and the model 478 "Snoopy" Neutron Monitor for measurement redundancy. The values shown in Table III were measured by the Harwell detector and corroborated by the "Snoopy". The gamma dose rate (1.5 mR/hr) measured at 1 meter at 0° for the 165 MeV ^{28}Si beam indicates that most of the dose is from neutrons."

TABLE III

NEUTRON DOSE EQUIVALENT RATES AT 1 METER AS A FUNCTION OF ANGLE

ION	(MeV)	(MeV/A)	Q	(Qna)	0°	20°	45°
^{12}C	100	8.33	6	35	80 mRem/hr	50 mRem/hr	40 mRem/hr
^{16}O	126	7.88	8	35	50 mRem/hr	30 mRem/hr	20 mRem/hr
^{28}Si	165	5.89	11	35	10 mRem/hr	6 mRem/hr	5 mRem/hr

"These results show that for even the lowest mass particles to be transported the radiation levels are less than 100 mR/hr. Accordingly, the area will be classified as a radiation area as defined in the BNL OH&S Guide 3.4.0. The test beam current intensities were chosen to reflect beams more intense than the design levels.

More recently, on 5/16/90, a similar test was performed with an oxygen beam in the HITL tunnel. Both neutron and gamma levels were monitored for a 13 nanoamp beam; the results of these tests (Appendix 7.8) confirm the previous findings of extremely low radiation levels.

4.3.3 Failure Mode Analysis

As is the case in HITL, the most probable failure mode during periods of normal beam transport is beam impingement on the interior of a beamline pipe due to a misadjustment or failure of a quadrupole focussing magnet or a steering magnet. This mode leads to a large beam "footprint" on the interior of the pipe, thus distributing the resultant radiation field over a large area of the tunnel and yielding lower local dose rates than the instance of total loss at a single point. The single loss-point case would most likely result from the beam hitting an inserted Faraday cup, closed vacuum gate valve or a dipole magnet vacuum chamber in the case of a dipole power supply loss. Moreover, the worst case geometry (0° from impact) occurs only at the two horizontal dipole positions.

It has been recognized that elevated radiation levels may result from either an electrical fault in the Tandem ion source, or from delivering the wrong beam species to the transfer line. The latter case is virtually impossible to occur accidentally since it would require deliberate and willful improper setting of ion source, accelerator and beam transport systems. Operating procedures to prevent the mounting of the wrong ion source or selection of improper species for acceleration are in place.

Tandem van de Graaff accelerators, while capable of accelerating virtually any ion species, are very sensitive to the total charge available for the acceleration process. Beam currents from the ion source can be injected into the Tandem at a maximum of several microamps DC; accelerated beam currents measured at the high energy end of the accelerator are higher in terms of "charge" current due to the increase in charge state from stripping at the terminal. (However, the total number of particles after acceleration is always somewhat reduced because the injection/acceleration/stripping processes have efficiencies less than unity.) If one were to continually increase the ion source current much above a level of several microamps, eventually the terminal voltage will "sag' as a result of the inability of the charging system to supply sufficient charge. The consequence of the terminal voltage decrease is a reduction in beam energy, and the resulting lower energy beam can not be transported around the analyzer magnet.

It has been found if the ion source is turned on for a very short period of time while operating at conditions capable of supplying very high currents, that pulses of beams of the order of 150 - 200 μamps for several hundred microseconds are possible. For a duty cycle of $1x10^{-4}$ (one 200 μsec pulse every two seconds), this corresponds to a DC equivalent beam current of about 20 nanoamps. Due to the fairly large capacitance of the terminal and the short duration of the pulses, these beams are capable of being accelerated through the Tandem before the terminal voltage droops. Following acceleration, a beam chopper is employed to increase the risetime of the pulse. This scenario describes the normal mode of operation for the heavy ion delivery to AGS or the Booster.

In preparation for a heavy ion run period, prior to activating the ion source pulser and beam chopper, the beamline is tuned using a very low-level DC beam (nominally 2 nanoamps). This mode allows maximum information to be gained from the instrumentation modules located along the beamline and reduces the time required to setup the transport.

Failure modes for both DC and pulsed operations have been investigated. If the DC beam current level is increased during setup, either from an electrical fault in the ion source or from operator error, the radiation levels at the high energy MP-7 radiation monitors will exceed a predetermined setpoint (presently 50 mRem/hr) and will result in interruption of the beam. This requirement can be met if the normal High Energy MP-7 radiation zone is operated in the non-set mode. Procedures are in place to ensure that this condition is met during HITL/HTB run periods. A planned future improvement is the installation of a dedicated fixed area monitor that interacts with only the HITL/HTB radiation safety system. This monitor will be permanently located at the image slits of the first 90° dipole bend into HITL. Even for good HITL transmission ions with charge-states other than that desired will impinge on the vacuum chamber walls or slits of this magnet, at which point the highest radiation levels are expected to be found. Detection of radiation levels exceeding an arbitrary level (say 50 mRem/hr), regardless of the status of the High Energy MP-7 zone, will interrupt beam transport by the insertion of the HITL beamstops.

Increases in ion source duty cycle during pulsed operation may also result in increased radiation levels for low mass beams. Previous models of ion source pulsers have had a recognized possible fault condition whereby the value of the resistor coupling the pulser to the ion source could change, conceivably resulting in the generation of rather high current DC beams. At some injected DC beam current, prior to reaching the point where the terminal voltage would no longer support acceleration, radiation fields within HITL/HTB could have reached hazardous levels. A worst case scenario based on maximum beam current cannot be performed because damage to the accelerator may result, but predictions have been made and studies performed. A memo from P. Thieberger to C. Gardner describing this scenario is included as Appendix 7.4. In this study the maximum radiation postulated was 8.9 Rem/hr at 1 foot and 0° from impact for a 10 μamp Si beam injected into MP-7. The scenario presumed a failure in the ion source pulser power supply. Since this study was done, a new method of pulser/ion source coupling utilizing a transformer has been implemented, eliminating this failure mode.

An increase in either frequency or length of the signal sent to the ion source pulser may also result in increased radiation levels. This signal is derived from the AGS t_0 timing pulse, and an increase in frequency is limited by the hold-off and turn-on time delay circuits to a maximum of 4 Hz, an increase in duty cycle of only a factor of ≈ 8. If the pulse length is somehow increased, the time constants in the ion-source pulser are such that for an arbitrary increase in driving signal, the output signal will be shorter than 1 ms, a five-fold increase in duty cycle. Note that in both these cases if fault conditions result in increased radiation levels, the radiation detection device interaction described above provides another layer of redundancy.

Studies have also been performed regarding radiation entering the HTB structure from the Linac and Booster (and vice-versa); the results of the shielding calculations and fault studies can be found in Appendices 7.5, 7.6 and 7.7.

4.3.4 Intended Operation Mode

The operational conditions using beams that could possibly produce radiation levels of any concern are expected to occur less than 5% of the projected 10 week/year heavy ion program. The emphasis is expected to continue to be on the delivery of the heaviest possible ions. Operationally, the maximum acceptable loss of transmitted beam current before re-tuning is required will be on the order of 20%. This lost beam, if any, will be distributed over a substantial length of the tunnel, thus lowering the local dose rate to less than one tenth of that expected from the 20% beam loss, or approximately 2.0 mRem/hr at any point.

4.3.5 HTB Radiation Safety System

After completion of the commissioning of the beamline, the HTB will logically be simply an extension to HITL. Occupancy levels during periods of no beam transport will be minimal; during tuning and transport the entire tunnel will be a total exclusion zone with locked and interlocked gates at all entrances. A training program for the issuance of gate keys to responsible, trained personnel is in place. Considering the modest radiation levels and the requirement that the tunnel be an exclusion area during transport, risk of radiation exposure to personnel is negligible. Adherence to these principles precludes the necessity of fixed-area radiation detectors, thus reducing system complexity and avoiding the maintenance problems associated with them.

The HTB interlock system is constructed using hard-wired relay logic for maximum reliability, with computer interaction only necessary for status monitoring and display. All circuits are designed to be failsafe, e.g. loss of control power or component failure will stop beam transport in a redundant manner. Distributed control power for the existing HITL radiation safety system is supplied through a motor-generator set, thus avoiding the need for re-securing the area after short term power outages or dips in line voltage. The HTB system power has been extended from this source. A map-type graphics panel that displays zone and interlock status is located in the Tandem Control Room.

As in HITL, the HTB tunnel is divided into several contiguous zones so that, following the initial search and zone setting process, only those areas having been physically entered during short term program interruption need be again searched and secured. Otherwise, searching the whole tunnel after such entry would require over a one-mile walk. Therefore zones are nominally 150' in length and are delineated by barriers (in the form of physical gates at entry points, and by light beams within the tunnel). Each zone has a barrier at each boundary, and each barrier has two pushbutton activation stations associated with it; one within the zone and one immediately outside it. A zone is set by activating the internal station at one end of the zone, searching the area for personnel while walking to the other end of the zone (activating midzone stations enroute), and then activating the remaining internal station at the far end. The operator will thus be in an area that is "semi-set", i.e. all internal stations will have been activated, thus denoting that the entire area within the zone has been searched. However, the operator will still be physically within the zone, and may then exit the zone by any path desired. When exiting he will necessarily break the barrier associated with that particular exit point and must then activate the external station associated with that particular barrier in order to fully "set" the zone. The internal search, as well as the exiting procedure, must be completed within strict time limits controlled by time delay relays. Exceeding the time limit forces the zone to revert to a completely "non-searched/secured" condition.

Note that if more than one zone is to be set, the search/set procedure continues logically into the next contiguous zone, since the external station that sets the exited zone is also an internal station of the next zone. Intrusion into a partially set zone during the setting procedure causes that zone to revert to its unset status.

Additionally, the primary tunnel lighting within each zone is extinguished upon bringing the zone to a set condition. This action results in a warning in the unlikely event that someone may have been overlooked by the primary search. Constant low-level background lighting is provided to allow safe exit in this case. (Battery-powered emergency lighting units are also provided throughout the entire complex to allow safe exit in case of power failure.)

Normal access to HTB is from two points - the HITL end of the tunnel, and the HTB power supply building (941). Unauthorized entry into the tunnel is prevented by means of a locked and interlocked gate installed within Power Supply Building 941 . This arrangement allows maintenance personnel to have access to equipment needing repair within the Electrical Equipment portion of the building, yet prevents them from entering the beam transport tunnel. The gate can always be opened (without a key) from the tunnel side to allow emergency exit.

Unauthorized entry into any zone during beam operation will break a barrier, causing beam stoppage through the insertion of redundant Faraday cups at the entrances of both the first and second 90° magnets located at the Tandem end of the tunnel. These Faraday cups are utilized as beam stops for many operational conditions and are kept inserted whenever personnel enter the tunnel zones. One Faraday cup actuator is of spring-loaded fail safe design that will revert to the inserted position in the unlikely event of power or compressed air loss.

Another possible, though unlikely entry point into the HTB tunnel is through the emergency exit door near the Linac tunnel. Entrance through this door would only be attempted in times of emergency using forcible entry techniques. Any entry through this door will violate the associated tunnel zone and cause the Faraday cup to be inserted, thus eliminating any possible exposure hazard to emergency forces.

Another level of safety is provided in the form of a "Beam Crash" system, similar to the existing TVDG Emergency Stop system. Lighted pushbuttons located throughout the tunnel can be activated in times of emergency. Activation of a Crash button will not shut down the Tandem accelerators, but will stop the beam by inserting the Faraday cup and will also notify the Tandem Control Room that a problem (such as an injury) has occurred. Upon notification, the operator will attempt to establish communications with the affected area and will dispatch an investigation team to resolve the problem.

At the Linac penetration point, consideration has been given to proper treatment of Linac-produced radiation affecting the HTB tunnel, as well as radiation from Tandem beams entering the Linac vault. The HTB beamline penetration through the Linac berm and tunnel wall has been accomplished by positioning the 3.6" dia. beamline pipe in the center of a 24" diameter, 25' long, steel pipe. Calculations of the expected radiation levels within HTB due to a Linac fault, using this geometry, indicated that additional shielding would be required. Twenty eight inches of high density concrete shielding block was added between the HEBT beamline and the linac vault wall in this area. Due to the local geometry, the line-of sight shielding thickness is more than 51 inches. Additionally, four feet of sand contained within fireproof sandbags has been packed around the HTB beampipe at either end of the penetration, providing another 8' of shielding material (refer to Fig. 6.7). The HTB and HEBT beamlines are separated vertically by about 6", further decoupling the radiation sources by reducing line-of-sight source geometry. Calculations by E. Lessard using similar shielding values and beamline geometries predicted moderate radiation levels within HTB due to a Linac fault. See Appendix HTB-7.4 for a complete discussion of the calculations. Fault studies of the actual radiation levels due to intentional beam loss in the Linac beamline has been conducted to confirm the predicted levels. Appendix 7.7 summarizes the results of the fault studies. A similar exercise was performed for the Linac/Booster junction; see Appendix 7.5 for this memo. In response to predictions and fault studies, as well as HITL experience, the entire HITL/HTB tunnel complex (excluding Power Supply House areas) is designated as a Radiation Area during heavy ion beam transport. The last 30' of the main HTB tunnel is additionally permanently posted as a Radiation

Area, since the Linac is a constant possible source of radiation during a fault.

To preclude injection of Tandem-produced heavy ion beams into Linac and Booster areas during Tandem diagnostic operation of HTB, two redundant beam stops have been located prior to the Linac penetration. The beam stops are fail safe, positive acting, remotely controlled devices capable of being removed from the closed position only from the AGS control room. These beam stops are the primary method of beam interruption and protection of Booster and Linac areas during HTB operation, and are fully described in the Booster SAR.

4.4 MAGNETIC FIELDS

Stray field concerns for magnets relate to the possibility of persons with pacemakers or other prostheses coming into contact with magnetic fields that may adversely affect the devices. ACGIH routine occupational TLVs for exposure to static magnetic fields are given as 600 gauss for whole body exposure, 6000 gauss extremity exposure on a daily, time-weighted average basis. Workers with implanted pacemakers should not be exposed to fields above 10 gauss.

The magnets used to transport heavy ion beams through HTB generally are of three designs: dipole bending magnets, quadrupole focussing magnets and small x-y steerer (trim) magnets. The quad and trim magnets are identical to those used in HITL, and the dipoles are of the same design but have a smaller bending angle than those in HITL.

Stray fields for HITL magnets have been measured at maximum excitation. At chest level, the quadrupoles are about 450 gauss @ contact and 40 gauss @ 1 foot from the magnet. The steerers have stray fields of 200 gauss @ contact and 5 gauss @ 1 foot. The dipoles typically have fields of 250 gauss @ contact and 60 gauss @ 1 foot.

Although personnel are excluded from the tunnel during periods of beam transport, there is no requirement that magnets be de-energized during occupancy. For most beams tunes the operating levels are generally from 10%-50% of maximum excitation. The need to work on or around the magnets during times when they are excited is negligible, therefore the exposure probability is very small. Levels exceed those recommended for pacemaker-wearers, but do not exceed those for occupational exposures, therefore all entrances to beamline areas are posted as being potentially hazardous to those wearing pacemakers.

5.0 RISK ASSESSMENT

As previously discussed in Section 4.0, an analysis of the possible safety and health hazards related to the HTB leads to the conclusion that fire and radiation are the risk pathways of possible concern. Asphyxiation was identified as a risk factor in HITL, but is not considered a factor in HTB. The safeguards are intended to assure that property damage and the hazards to personnel have been minimized and present an acceptable risk to the Laboratory and DOE.

5.1 FIRE

5.1.1 Threats to the Public Health or Welfare and Hazards to Life

The objectives of having no threats to the public health and welfare and no undue hazards to life from fire will be satisfied by the following:

1. The HTB complies with the intent of the 'Life Safety Code' (NFPA 101, Revised 1988) and with the specific requirements of the Occupational Safety and Health Standards (CRF 29, Part 1910) applicable to exits and fire protection features. In a building used for low or ordinary hazard special purpose industrial occupancy, NFPA 101, Section 28-2.6.3 permits travel distances up to 300 feet to the nearest exit.

2. Smoke and heat venting is provided to ensure that employees are not overtaken by spread of fire or smoke within six feet of floor level before they have time to reach exits. Smoke and heat venting is in accordance with Guide for Smoke and Heat Venting (NFPA 204).

3. The low combustible loading within HTB and the lack of continuity of combustibles will make rapid fire development unlikely. Cabling for HTB is a fire retardant type with CSPE jacketing wherever possible. Smoke detection throughout the tunnel will make it likely that fires will be rapidly detected in

their incipient stages. The smoke exhaust system, activated by the smoke detectors, assures early exhausting of smoke. The limited number of occupants (normally zero, occasionally five or less) and the administrative controls on tunnel occupancy place few at risk.

4. The potential for fast spreading fires is diminished by severe restrictions on the ratings of interior finish materials for flame spread and smoke development ratings, and by strict administrative controls on hazardous materials entering the facility (flammable liquids, flammable gases, toxic materials).

5. A credible fire will not be likely to release hazardous amounts of toxic materials or toxic combustion products. Offsite releases are therefore not credible.

6. Liquid runoffs from a credible fire will not be contaminated, nor are polluting liquids likely to escape the site, including water resulting from firefighting.

5.1.2 Unacceptable Program Delays

The Department of Energy considers it unacceptable to suffer impairment of a vital program due to fire losses for a period exceeding six months. In the case of HTB, the maximum credible fire loss (a dipole magnet) will not result in loss of use of the facility for a period longer than three months, well within the DOE criteria limit.

5.1.3 Property Damage Limitation

The objective of limiting property loss will be satisfied as follows: The probable property loss from a credible fire does not exceed $65,000; the maximum possible loss is less than $204,000; both are well within the DOE limits of $250,000 and $1 million, respectively. Automatic fire extinguishing capability to meet these criteria is not required. Refer to Appendix 7.2 for valuation of equipment in Bldg. 941.

HTB SAR
RISK ASSESSMENT

SYSTEM: HTB TRANSPORT BEAMLINE AND STRUCTURES
SUB-SYSTEM: None

HAZARD: Fire

Hazard impact: Threat to life; loss of equipment; programmatic interruption.

Risk assessment prior to mitigation:

Hazard severity: ☐ I (Catastrophic) ☐ II (Critical) ☒ III (Marginal) ☐ IV (Negligible)

Probability: ☐ A (Frequent) ☐ B (Probable) ☐ C (Occasional) ☒ D (Remote) ☐ E (Extr. remote) ☐ F (Impossible)

Risk Category: ☐ 1 (High Risk) ☐ 2 (Moderate Risk) ☒ 3 (Low Risk) ☐ 4 (Routine Risk)

Mitigating factors: Installation of fire standpipe; siting of sprinkler over major concentrations of experimental equipment; administrative control over introduction and storage of flammables.

Risk level following mitigation:

Hazard severity: ☐ I (Catastrophic) ☐ II (Critical) ☒ III (Marginal) ☐ IV (Negligible)

Probability: ☐ A (Frequent) ☐ B (Probable) ☐ C (Occasional) ☐ D (Remote) ☒ E (Extr. remote) ☐ F (Impossible)

Risk Category: ☐ 1 (High Risk) ☐ 2 (Moderate Risk) ☐ 3 (Low Risk) ☒ 4 (Routine Risk)

Additional Comments: None.

TVDG Review Status: ☐ Open
☒ **Closed By:** T. Robinson **Date:** 6/19/91

APPROVALS:

TVDG Safety

TVDG Group Leader

5.2 RADIATION

The radiation risk presented by the HTB project is minimal and well within permissible limits. The combination of safety procedures which have been used successfully at the Tandem Van de Graaff/HITL complex and the levels of radiation which would be produced even under the maximum failure mode constitute an acceptable risk.

As discussed in Section 4.3.5 the personnel access control systems and their related procedures prevent unauthorized access and minimize exposure of operations or maintenance personnel. The risk will further be minimized by the fact that operations that will produce any significant radiation are expected to be less than 5% of the total projected program. Emergency beam crash buttons located throughout the tunnel add an additional level of safety.

Radiation resulting from a Linac incident and introduced into HTB through the beamline penetration into the HTB tunnel is an identified potential hazard as discussed in Section 4.3.5. A fault study has been conducted to ascertain the extent of this hazard, and appropriate steps have been taken to reduce radiation levels to acceptable values. Refer to Appendices 7.5, 7.6, 7.7 and Fig. 6.7.

HTB SAR
RISK ASSESSMENT

SYSTEM: HTB TRANSPORT BEAMLINE AND STRUCTURES
SUB-SYSTEM: ION BEAM TRANSPORT

HAZARD: Beam-produced radiation

Hazard impact: Personnel exposure as a result of production of radiation levels above that approved for present shielding values.

Risk assessment prior to mitigation:

Hazard severity: ☐ I (Catastrophic) ☐ II (Critical) ☒ III (Marginal) ☐ IV (Negligible)
Probability: ☐ A (Frequent) ☐ B (Probable) ☐ C (Occasional) ☒ D(Remote) ☐ E (Extr. remote) ☐ F (Impossible)
Risk Category: ☐ 1 (High Risk) ☐ 2 (Moderate Risk) ☒ 3 (Low Risk) ☐ 4 (Routine Risk)

Mitigating factors: Administrative control of ion species to be accelerated; construction of a decoupled high voltage pulser to avoid failure-mode DC beams; future installation of an interlocked fixed-area radiation monitor prior to injection into the transport tunnel to limit radiation levels.

Risk level following mitigation:

Hazard severity: ☐ I (Catastrophic) ☐ II (Critical) ☒ III (Marginal) ☐ IV (Negligible)
Probability: ☐ A (Frequent) ☐ B (Probable) ☐ C (Occasional) ☐ D (Remote) ☒ E (Extr. remote) ☐ F (Impossible)
Risk Category: ☐ 1 (High Risk) ☐ 2 (Moderate Risk) ☒ 3 (Low Risk) ☐ 4 (Routine Risk)

Additional Comments: None.

TVDG Review Status: ☐ Open
☒ **Closed By:** T. Robinson **Date:** 6/19/91

APPROVALS:

TVDG Safety

TVDG Group Leader

5.3 ASPHYXIATION

In the HITL FSAR it was recognized that the possibility existed for asphyxiation of personnel within the eastern portion of HITL due to a broach of a Tandem accelerator vessel, which could introduce SF_6 insulating gas into the tunnel.

However, due to the relatively small volume of available gas, the small probability of a massive leak, and the extreme separation between the source of the gas and HTB, (approximately 2000'), asphyxiation is not considered to be a risk factor in HTB.

5.4 ENVIRONMENT

A review of the HTB project with respect to NEPA compliance was performed by S&EP on 2/14/89. The cover letter and evaluation form resulting from this review can be found in Appendix 7.3. The project has been evaluated for compliance with the appropriate sections of the Clean Air Act, and it has been determined that the emissions are substantially lower than the level required for a NESHAPs permit. The cover letter stating this position can be found as Appendix 7.9.

5.5 OPERATIONAL SAFETY LIMITS

Operational Safety Limits (OSLs) have been established for the HTB beamline, including Limiting Conditions for Operation (LCOs). Included are OSLs for;

1. Minimum particle mass limitation.
2. Maximum beam power limitation.
3. Functional fire detection or suppression systems.
4. Functional Radiation Safety/Access System.
5. Minimum of 2 Operators during operation.

Refer to the following pages for details regarding these OSLs.

OPERATIONAL SAFETY LIMIT (OSL-HTB 1.0) Tandem Van de Graaff/HTB

SYSTEM REQUIRING AN OPERATIONAL SAFETY LIMIT:

HTB Beam Transport.

PURPOSE OF THE OPERATIONAL SAFETY LIMIT:

To limit radiation fields within the HTB complex that may result from acceleration of the lower mass heavy ion beams available from the Tandem Van de Graaff. At Booster injection energies particles having masses of lower than that of Carbon (12 amu) may have associated radiation levels exceeding that described in the present HTB SAR.

OPERATIONAL SAFETY LIMIT:

This Operational Safety Limit establishes that the minimum mass beam allowed to be introduced into the HTB complex is mass 12 (Carbon).

REQUIREMENTS

1. *Design Features.* The complexity of the Tandem Van de Graaff accelerators and their associated beam transport systems effectively preclude accidental acceleration and/or delivery of unknown or unwanted species. In many cases low mass particles require special ion source set-ups, and may even dictate a different ion source be mounted in the Negative Ion Injector, with attendant vacuum and high voltage system shutdown and restoration. In addition, many dozens of transport magnets require re-tuning to successfully transport an unwanted beam to the HTB area.

2. *Safety Limits.* The Safety Limit for this OSL is set at the mass of Carbon (12 amu). Ion beams having mass less than this value shall not be transported through HTB.

3. *Administrative Controls.* The Tandem Group Leader and Operations Supervisor shall neither schedule nor allow beams of less than mass 12 (Carbon) to be introduced into the HTB complex. They, and in their absence the Operations Shift Supervisors, shall ensure that ion source, transport and accelerator parameters resulting in the introduction and/or transport of beams having mass lower than Carbon are prohibited.

TVDG Safety

TVDG Group Leader

OPERATIONAL SAFETY LIMIT (OSL-HTB 2.0)
Tandem Van de Graaff/HTB

SYSTEM REQUIRING AN OPERATIONAL SAFETY LIMIT:

HTB Beam Transport.

PURPOSE OF THE OPERATIONAL SAFETY LIMIT:

To prevent Tandem Van de Graaff beams having an average power rating of greater than 300 watts from being introduced into HTB. The HTB beamstops (under AGS control) used to prevent heavy ion beams from entering either the Linac or Booster areas are rated at 300 Watts maximum power dissipation.

OPERATIONAL SAFETY LIMIT:

This Operational Safety Limit establishes that the power associated with ion beams introduced into HTB is limited to 300 watts or less.

REQUIREMENTS

1. *Design Features.* Beam power associated with Tandem beams is defined as the product of the beam energy and the average beam particle current. Maximum attainable energies are equal to q+1 (q= charge state at the terminal) times the terminal voltage, which for sustained operations is limited to 15 MV. For higher mass particles, this energy corresponds approximately to 1 MeV/amu. Under fault conditions, maximum beam current delivered to HTB is hardware limited to approximately 10 particle microamps of any particular charge state (DC equivalent) following momentum selection in an analyzing magnet; the normal pulsed mode of operation utilizes beam currents typically 3 to 4 orders of magnitude less intense. Accelerator terminal charging current limitations as well as stripping and transport efficiencies thus presently preclude beam powers, even under fault conditions, in excess of approximately 200 watts.

2. *Safety Limits.* The Safety Limit for this OSL is set at a beam power of 300 watts. As a Safety Set Point, beams having power ratings greater than 200 watts shall not be utilized in HTB.

3. *Administrative Controls.* The Tandem Group Leader and Operations Supervisor shall neither schedule nor allow introduction of beams having a power rating (beam energy x average particle beam current) of more than 200 watts into the HTB complex. They, and in their absence the Operations Shift Supervisors, shall ensure that ion source, transport and accelerator parameters that result in HTB beams with power ratings exceeding 200 watts are prohibited.

TVDG Safety

TVDG Group Leader

SECTION 6

FIGURES

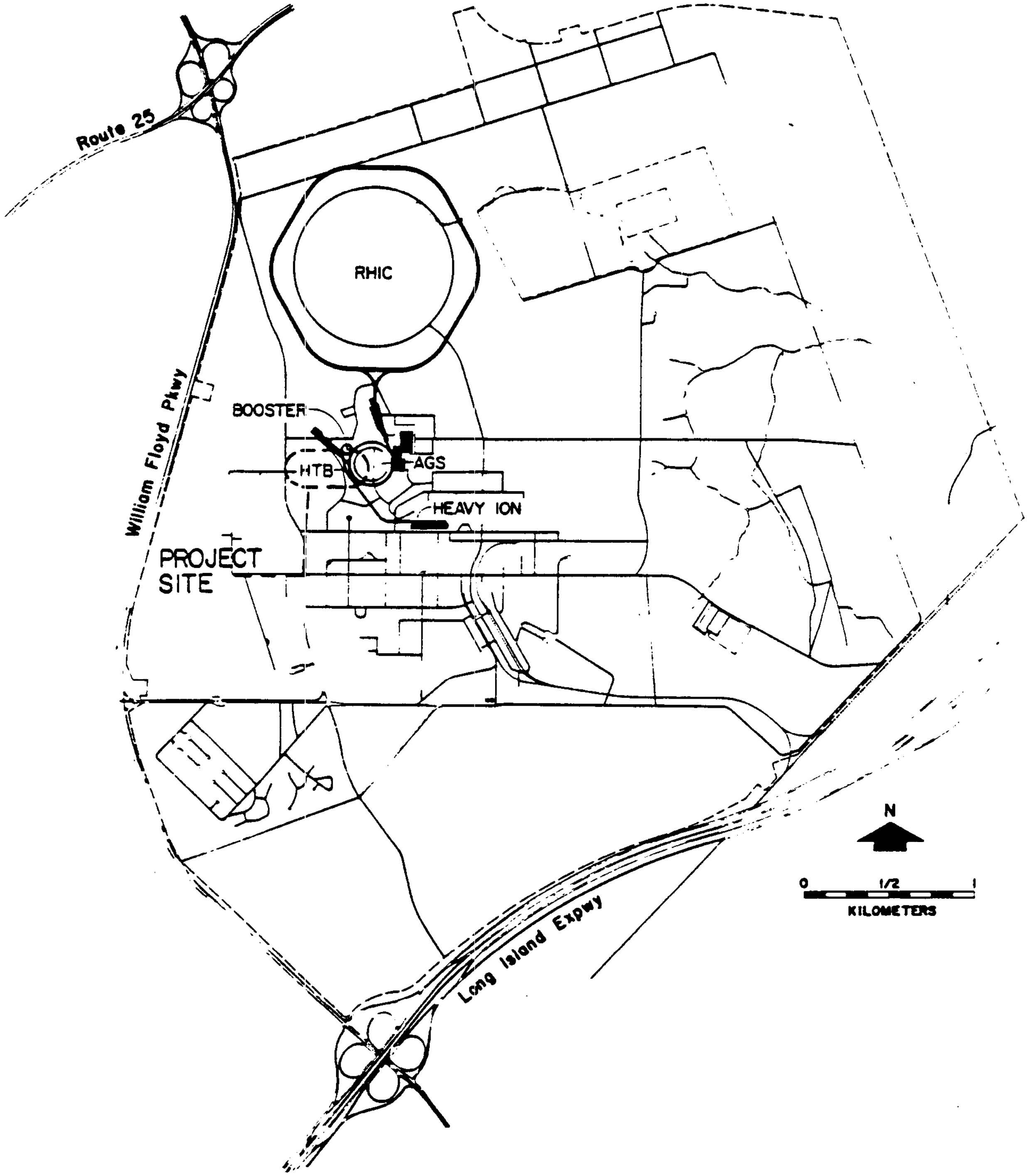
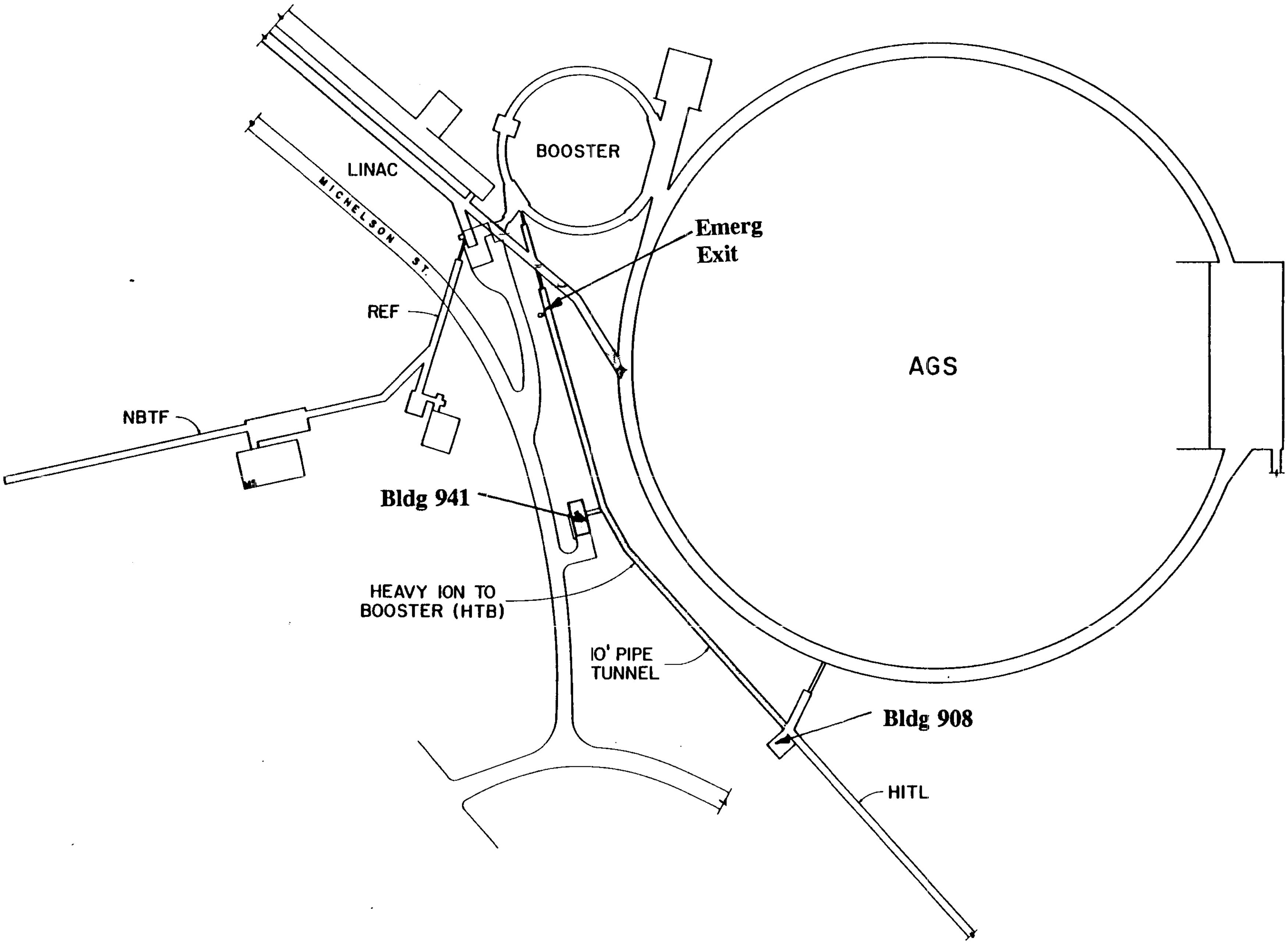
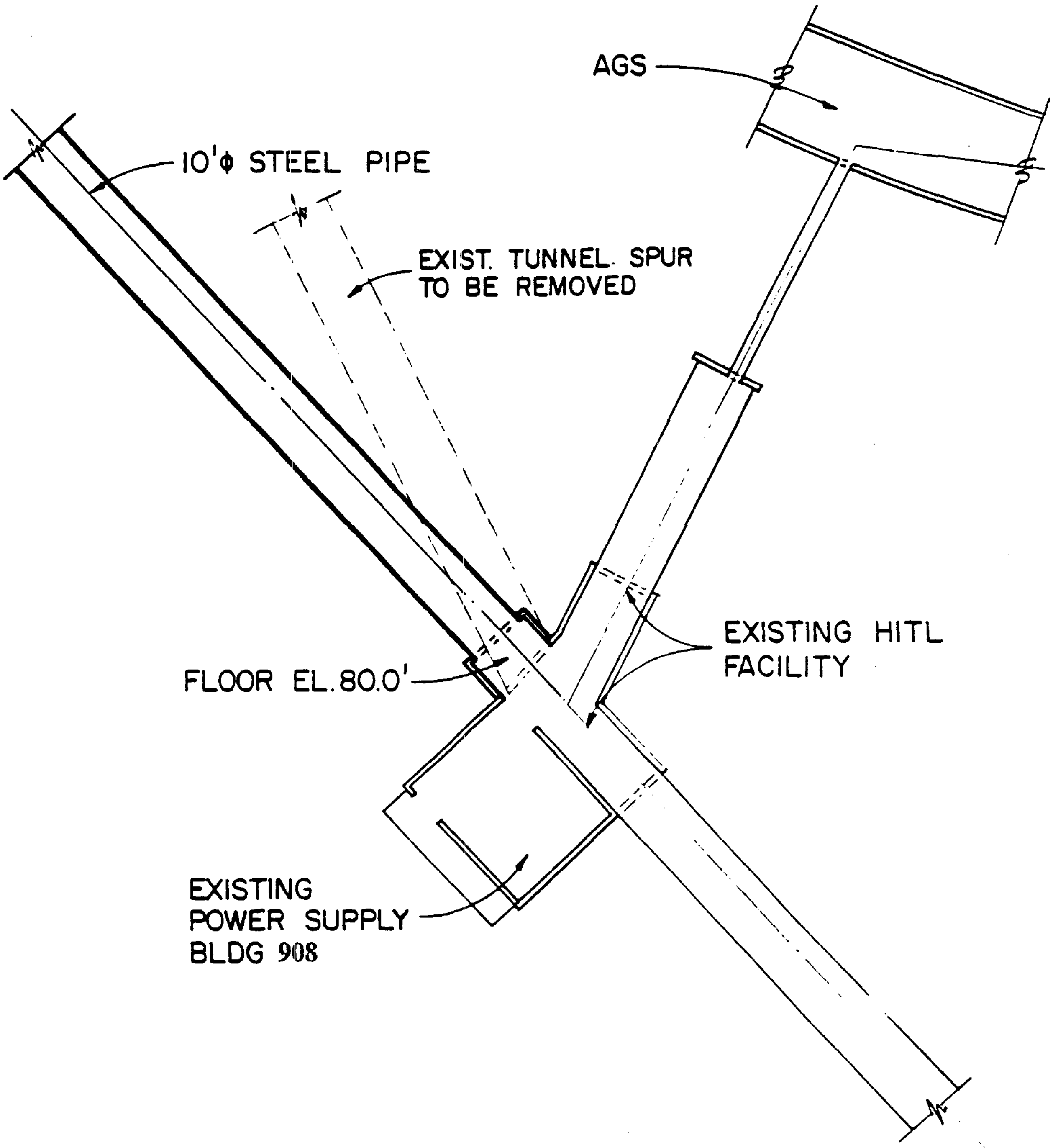

Route 25
RHIC
William Floyd Pkwy
BOOSTER
HTB
AGS
HEAVY ION
PROJECT
SITE
N
0
1/2
1
KILOMETERS
Long Island Expwy

Fig. HTB-6.1



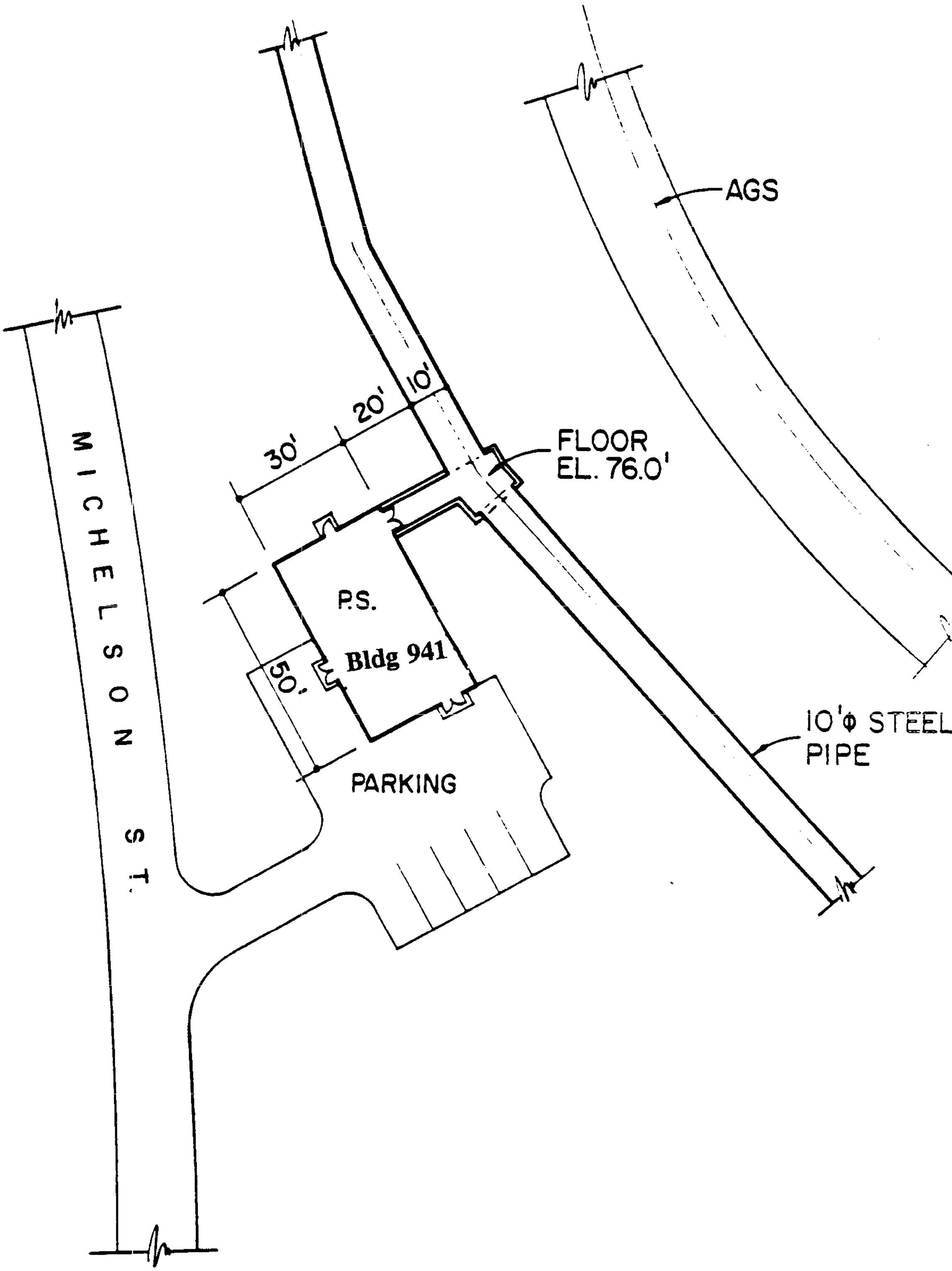
SITE PLAN

Fig. HTB-6.2



HTB TIE IN AT EXISTING HITL

Fig. HTB-6.3



HTB MID-POINT BUILDING

Fig. HTB-6.4

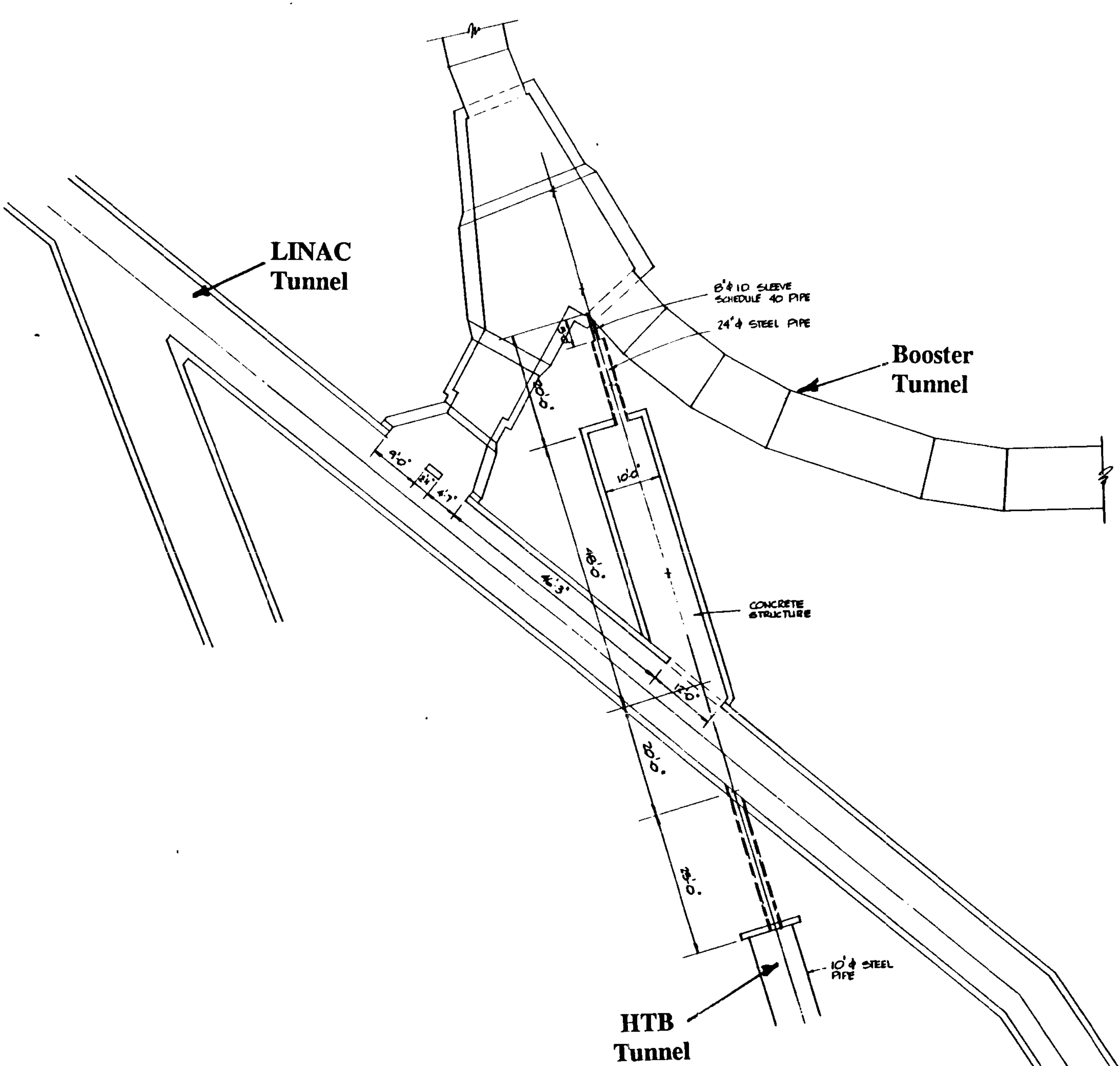
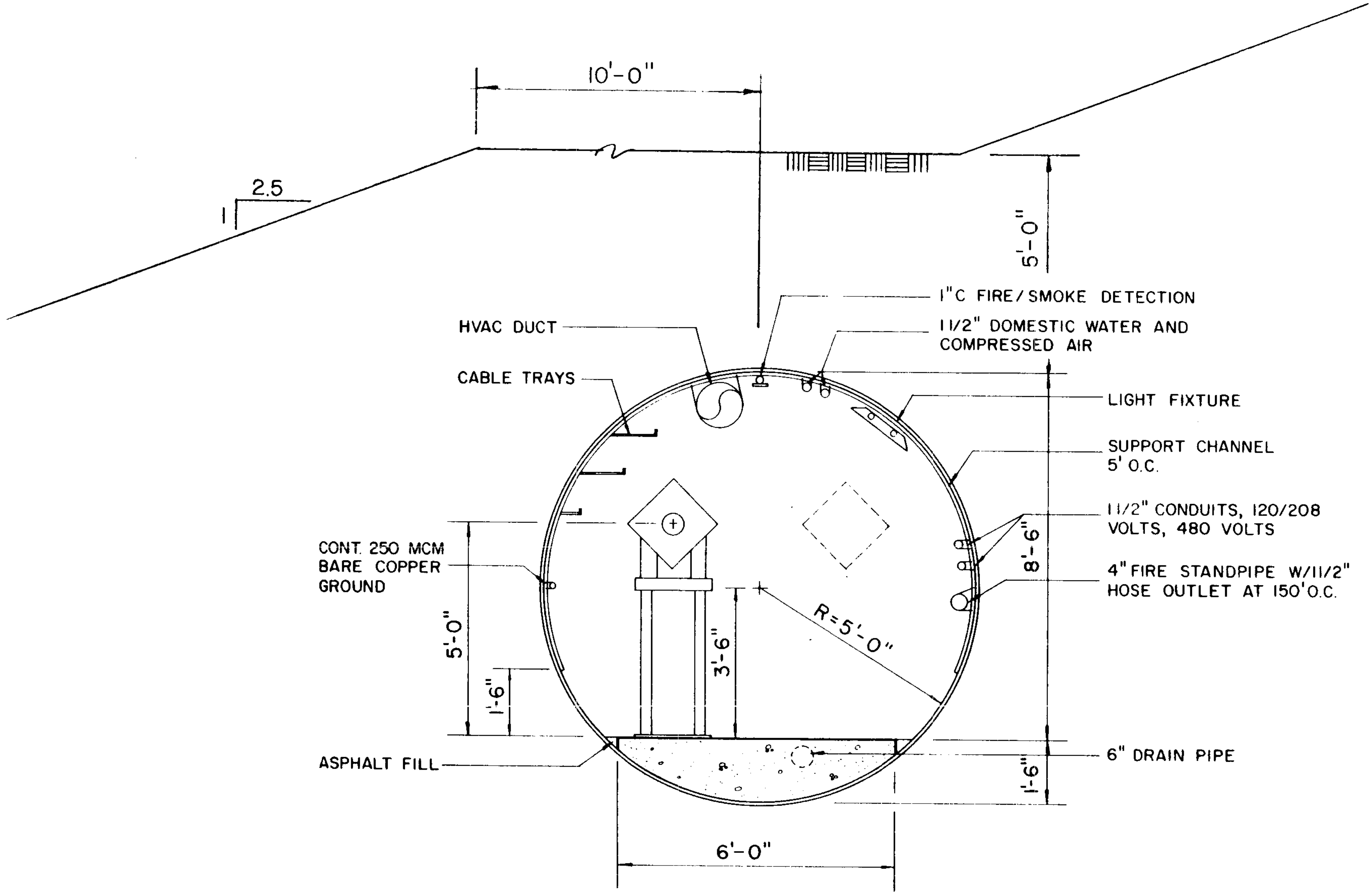

LINAC
Tunnel
Booster
Tunnel
HTB
Tunnel
CONCRETE
STRUCTURE
10'0"
9'0"
4'7"

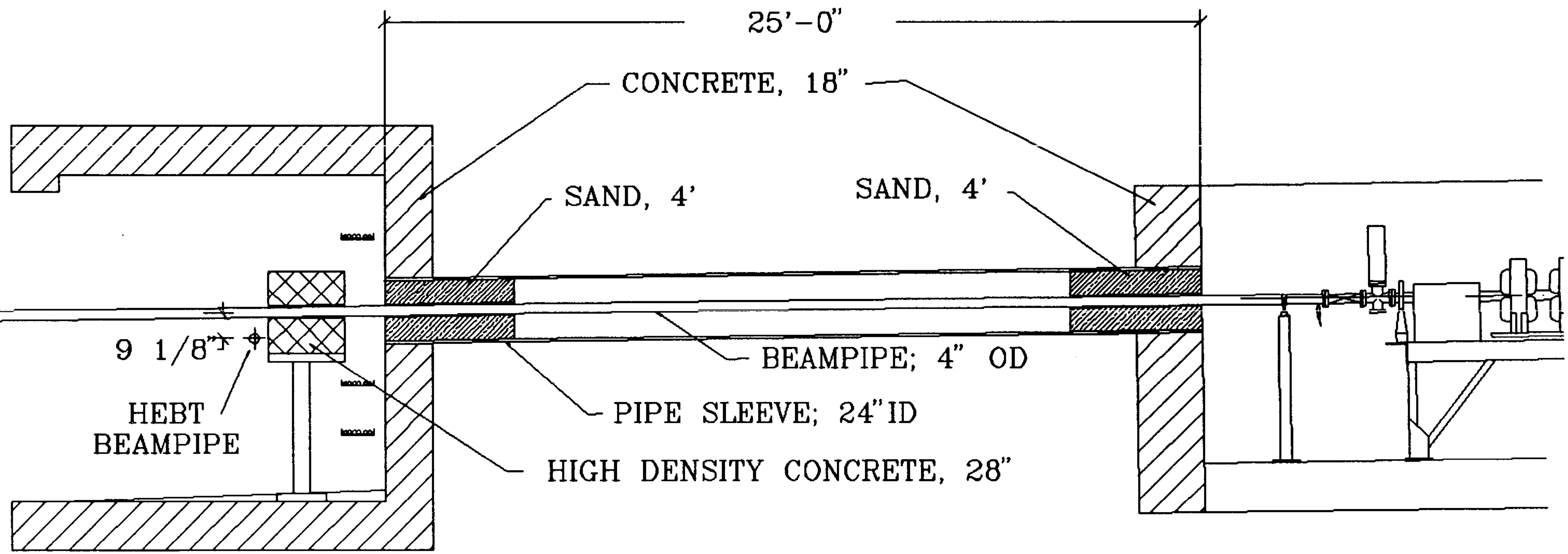
Fig. HTB-6.5



TUNNEL CROSS SECTION

HTB

Fig. HTB-6.6



LINAC/HTB SHIELDING

Fig. HTB-6.7

SECTION 7

APPENDICES

HTB MAJOR DEVICE LOCATIONS

DEVICE NAME	NORTH FEET	EAST FEET	ELEV FEET	LINEAR FEET	LINEAR METERS
21 MW 152	101656.33	98796.05	84.98	2002.32	611.31
21 FC 152	101656.33	98796.05	84.98	2002.32	611.31
21 DV 1	101658.80	98793.82	84.97	2005.66	612.33
24 TDH 1	101660.66	98792.15	84.94	2008.16	613.09
24 QH 1	101715.55	98742.76	83.99	2081.99	635.63
24 QV 1	101716.66	98741.76	83.98	2083.49	636.09
24 TDV 2	101717.78	98740.75	83.96	2084.99	636.55
24 TDH 2	101718.77	98739.86	83.94	2086.32	636.95
25 TDV 1	101771.27	98692.62	83.04	2156.95	658.52
25 TDH 1	101772.26	98691.73	83.02	2158.28	658.92
24 MW 155	101773.41	98690.70	83.00	2159.82	659.39
24 FC 155	101773.41	98690.70	83.00	2159.82	659.39
25 QV 1	101830.15	98639.64	82.03	2236.16	682.70
25 QH 1	101831.26	98638.64	82.01	2237.66	683.16
25 TDV 2	101832.38	98637.63	81.99	2239.16	683.61
25 TDH 2	101833.37	98636.74	81.97	2240.49	684.02
25 XF 149	101885.89	98589.48	81.07	2311.14	705.59
25 MW 152	101887.63	98587.92	81.04	2313.48	706.30
25 FC 152	101887.63	98587.92	81.04	2313.48	706.30
26 DH 1	101889.89	98585.88	81.00	2316.52	707.23
26 TDV 1	101892.30	98584.56	80.96	2319.27	708.07
26 TDH 1	101893.47	98583.91	80.95	2320.60	708.48
26 QH 1	101917.62	98570.60	80.59	2348.19	716.90
26 QV 1	101919.38	98569.64	80.57	2350.19	717.51
26 MW 042	101924.92	98566.58	80.49	2356.52	719.45
26 FC 042	101924.92	98566.58	80.49	2356.52	719.45
26 QV 2	101930.47	98563.52	80.41	2362.85	721.38
26 QH 2	101932.22	98562.56	80.38	2364.85	721.99
26 TDV 2	101933.53	98561.83	80.36	2366.35	722.45
26 TDH 2	101934.70	98561.19	80.35	2367.69	722.85
26 MW 079	101957.29	98548.74	80.02	2393.48	730.73
26 FC 079	101957.29	98548.74	80.02	2393.48	730.73
26 DH 2	101959.96	98547.27	79.98	2396.52	731.66
27 TDV 1	101963.73	98546.21	79.93	2400.44	732.85
27 TDH 1	101965.01	98545.85	79.91	2401.77	733.26
27 QH 1	102036.57	98525.69	78.96	2476.11	755.96
27 QV 1	102038.01	98525.29	78.94	2477.61	756.42
27 TDV 2	102039.46	98524.88	78.92	2479.11	756.87
27 TDH 2	102040.74	98524.52	78.90	2480.45	757.28
27 XF 149	102105.79	98506.19	78.04	2548.03	777.91
28 TDV 1	102107.68	98505.66	78.02	2549.99	778.51

28 TDH 1	102108.96	98505.30	78.00	2551.32	778.92
27 MW 154	102110.44	98504.88	77.98	2552.86	779.39
27 FC 154	102110.44	98504.88	77.98	2552.86	779.39
27 Z 155	102111.81	98504.50	77.96	2554.28	779.82
27 Z 156	102111.81	98504.50	77.96	2554.28	779.82
28 QV 1	102155.23	98492.27	77.39	2599.39	793.60
28 QH 1	102156.67	98491.86	77.37	2600.89	794.05
28 TDV 2	102158.12	98491.45	77.35	2602.39	794.51
28 TDH 2	102159.40	98491.09	77.33	2603.73	794.92
28 MW 132	102240.03	98468.38	76.26	2687.49	820.49
28 FC 132	102240.03	98468.38	76.26	2687.49	820.49
29 QV 1	102243.37	98467.44	76.22	2690.97	821.55
29 QH 1	102244.82	98467.03	76.20	2692.47	821.55
29 TDV 1	102246.26	98466.62	76.18	2693.97	822.47
29 TDH 1	102247.54	98466.26	76.16	2695.30	822.88
29 QH 2	99653.21	99197.07	110.59		0.00
29 QV 2	99653.21	99197.07	110.59		0.00
29 DV 1	102334.96	98441.64	75.00	2786.12	850.60
					0.00
29 TDH 2	99653.21	99197.07			0.00
29 MW 128	99653.21	99197.07			0.00
29 FC 128	99653.21	99197.07			0.00
29 XF 130	99653.21	99197.07			0.00
BOOSTER INJ	99653.21	99197.07			0.00

Appendix 7.2

POWER SUPPLY AND INSTRUMENTATION VALUES IN BLDG. 941

Dipole Power Supplies	\$60,000
Quad Power Supplies	\$35,000
Steerer Power Supplies	\$37,000
NMR Gaussmeters	\$24,000
Control Electronics	\$35,000
Vacuum Electronics	\$10,000
Radiation Safety System	\$ 3,000
TOTAL	\$204,000

BROOKHAVEN NATIONAL LABORATORY

MEMORANDUM

DATE: February 14, 1989

TO: W. R. Casey

FROM: J. R. Naidu

SUBJECT: NEPA Compliance - Tandem Van De Graaff/Booster HITL to Booster (HTB) Project

I have reviewed the preliminary safety analysis report on the HTB Tunnel construction and also the engineering drawings pertaining to the construction of the facility. The following issues were identified and discussed and are summarized below:

1. Groundwater table fluctuations: The elevation of the bottom of the tunnel is well above the existing level of the groundwater table and as such this impact was not considered.

2. Potential for radioactivation of soil as a result of beam loss: The design of the facility - the tunnel - does not require the need for dumping beam lines within the tunnel structure. A conclusion was made that the potential for groundwater contamination does not exist.

3. Use and storage of chemicals, etc: No chemicals will be stored within the tunnel. Air-cooled transformers will be used in the beam line, as such the potential for spills of transformer oils will not be there.

4. The impact of the Wild, Scenic and Recreational Rivers System Act does not exist as demonstrated in the booster environmental analysis report, since this project is in the immediate vicinity of the booster.

I am using an environmental compliance form as out-lined in the Laboratory NEPA policy. The information given in this evaluation should satisfy the requirements of NEPA for the HTB project.

JN/md

Attachment

cc: T. Robinson w/attachment

Figure 1
Environmental Evaluation Form

Project Name: Tandem Van De Graaff/Booster HITL to Booster (HTB) Project

Project Locations: Tandem Van De Graaff/Booster

Laboratory Organization Initiating Project: ____

Project Phase: Identification and Formulation ____ Preliminary Design ____
Conceptual Planning and Design ____ Final Design X

Project Type: Operating Funded ____ Accelerator Improvement ____
Equipment Funded ____ Reactor Modification ____
Construction Line Item X In-House Energy Management ____
Other ____ General Plant Projection ____

Issue	Applicability: A	NA	Potential Impact: N	NAI	AI	Comment
Construction Activity:						
Dust			X			
Noise			X			
Other			-			
Effluents and Contaminants:						
Solids			X			
Liquids			X			
Gases			X			
Energy Emissions:						
Radiation			X			
Other			-			
Land Use Considerations:						
Wetlands/FloodPlains			X			
Critical Habitats			X			
Cultural Resources			X			
Other			-			
Facility Considerations:						
Aesthetics			X			
Public Relations			X			
Other			-			

Conclusions: Impact on Environment considered as insignificant.
NEPA Classification: Findings of No Significant Impact (FONSI).

Janakiram R. Naidu — 2-14-89

Laboratory Environmental Coordinator — Evaluation Date

Applicability: A - Applicable; NA - Not Applicable.
Potential Impact: N - none; NAI - No Adverse Impact (There could be an Impact, but the effect may not be harmful); AI - Adverse Impact.

Send completed copies to Project Manager/Coordinator.

BROOKHAVEN NATIONAL LABORATORY

M E M O R A N D U M

DATE: May 29, 1990

TO: C. Gardner

FROM: P. Thieberger

SUBJECT: Radiation estimates for Si beams

On May 24 a 186 MeV 3-stage Si beam was accelerated in the tandems and transported through HITL to 22DS1 in order to perform neutron and gamma radiation measurements. This was done by S&EP and tandem personnel to establish worst-case fault levels at one foot of a beam stop. The results are the following:

a) The radiation monitor located close to 11DH1 with a safety response level set at 100 mrem/hr neutrons will limit the total level at 1 foot and 0° of a beam stop to 150 mrem/hr.

b) A safely estimated maximum DC beam of 10 μA injected into MP7 would correspond to a level of 8.9 Rem/hr at 1 foot and 0° of a beam stop. Such a level could only occur if an unlikely fault in the ion source coincided in time with an even more unlikely failure of the radiation safety system. In the pulsed mode an additional failure of the chopper would also be required.

10 μA of DC beam injected into MP7 corresponds to ~100 μA at the high energy end of MP7. With the accelerator operating close to 15 MV, a column and/or tube breakdown is very likely to occur long before such levels are reached.

/sa

cc: Tandem Safety Committee

BROOKHAVEN NATIONAL LABORATORY

MEMORANDUM

DATE: April 27, 1989

TO: Ted Robinson

FROM: Edward T. Lessard ETL

SUBJECT: Radiation Hazard from a Fault at the HTB and Linac Intersection

Summary

The HTB headwall and beam line near the Linac have sufficient shielding to meet the Laboratory design guidelines for a 'high radiation area' designation.

Methods

The following are facts relevant to shield thickness. Based on design, a shield wall with a minimum thickness of 2 feet iron and 3 feet of borated paraffin separates the HTB tunnel and the Linac. A penetration in the form of a beam pipe through the shield wall exists and is 4 inches in diameter. Between the shield and the HTB headwall, a 24-inch diameter pipe contains the 4-inch beam pipe (See Figures One and Two. Figures are provided by T. Robinson, Physics Department). Additionally, a 0.5 foot thick iron shield will be placed in the space between the HTB line and Linac line for a length of 2 feet, and is to be centered about the HTB line.

The following are facts relevant to proton loss. The beam height in the Linac is at elevation 75 feet. The HTB beam crosses the Linac beam at a 34° angle, but is at elevation 75 feet 9.5 inches. The headwall of the HTB beam line is 30 feet from the Linac beam. Linac protons are not planned to be lost at the HTB/Linac cross point. The maximum proton output of the Linac is 2×10^{18} protons per hour at an energy of 200 MeV. When the protons become unstable due to disruptive accelerating forces, beam losses are spread over a distance of 100 feet. When loss of the quadrupole focusing system occurs, the beam is lost in a distance of about 30 feet (1). To approximate a small area loss, I assume 7% of the full Linac output is lost at a point near the HTB 24-inch pipe. One would not run for significant periods of time in a fault condition.

For 200 MeV energy particles, the following formula (2, 3, 4) is used to calculate dose equivalent through shields at 90° relative to the direction of the protons:

$H = 4.5\times10^{-17}\, P\, e^{-(b/70 + i/147 + a/140)} / r^2$ for a point source.

In this equation, the symbols mean:

H = dose equivalent, Sv
P = number of protons lost at a point, protons
b = mass density thickness of borated paraffin, g/cm^2
i = mass density thickness of iron, g/cm^2
a = mass density thickness of air, g/cm^2, and
r = distance to point of interest, m.

For an angle of 34° with respect to a point loss of protons, the number of secondary radiations is increased by a factor of 10 relative that at 90° (2). The increased line-of-sight thickness of iron at 34° results in an additional factor of 12 for dose reduction. These two factors off set each other and the above formula is used here.

For calculational purposes, the densities of materials are: 0.9 g/cm^3 for borated paraffin, 7.8 g/cm^3 for iron and 0.001293 g/cm^3 for air. The dose-reduction mean free path for iron, 147 g/cm^2, is assumed to be appropriate for iron followed by paraffin. The dose-reduction mean free path for paraffin is assumed to be identical to earth, 70 g/cm^2. In the vertical space between the 2 beam lines, only iron exists. The dose-reduction mean free path for this iron is assumed to be 200 g/cm^2, rather than 147 g/cm^2, since this iron is not followed by material which absorbs low energy neutrons.

The dose reduction in a straight access way has been examined by Tesch (5) for two different source positions. At 10 meters from the source, the reduction in dose was proportional to the inverse square of the distance for a source position in line of site with the access-way opening. For a source position off the line of site, Tesch measured a reduction in dose by an additional factor of 10 for a 10 meter length of access way. This additional factor of 10 is used to estimate the reduction in dose through the HTB beam pipe since this pipe is not in line-of-site with the position where protons are assumed to be lost. This reduction factor is not used for the 24-inch pipe since it is in line of site with the Linac beam.

Results

Part-time or full-time occupancy at the surface of the HTB headwall is not assumed since continuous occupancy of the HTB line is not planned. Because of possible fault levels greater than 100 mrem in 1 hour, the HTB headwall area should be considered a potential 'high radiation area', and should conform with the specifications in the BNL Occupational Health and Safety Manual which are listed for an area of this type.

The dose equivalent rates for a 7% of maximum Linac output lost at the HTB/Linac cross point are:

Location in HTB Tunnel	Fault Dose Equivalent Rate, rem in 1 hour
24-inch pipe at HTB headwall	<0.1
4-inch beam pipe at HTB headwall	<0.4

Dose estimates are rounded to 1 significant figure.

Copy to:

J. Glenn
D. Lowenstein
S. Musolino
N. Rohrig

1. G. W. Wheeler and W. H. Moore, Shielding of the 200-MeV Linac, Brookhaven National Laboratory Report, AGSCD-10, Accelerator Department Internal Report, May 18, 1966.

2. K. Tesch, "A Simple Estimation of the Lateral Shielding for Proton Accelerators in the Energy Range 50 to 1000 MeV," Radiation Protection Dosimetry, V11, pp. 165-172, 1985.

3. K. Tesch, "Comments on the Transverse Shielding of Proton Accelerators," Health Physics, 44, pp. 79-82, 1983.

4. S. Ban, H. Hirayama, K. Kondo, S, Muira, K. Hozumi, M. Tiano, A. Yamamoto, H. Hirabayashi, and K. Katoh, "Measurement of Transverse Attenuation Lengths for Paraffin, Heavy Concrete and Iron around an External Target for 12 GeV Protons," Nuclear Instruments and Methods 174, pp. 271-276, 1980.

5. K. Tesch, "The Attenuation of the Neutron Dose Equivalent in a Labyrinth Through an Accelerator Shield," Particle Accelerators, V12, pp. 169-175, 1982.

BROOKHAVEN NATIONAL LABORATORY

MEMORANDUM

DATE: June 5, 1989

TO: Ted Robinson

FROM: Edward T. Lessard ETL

SUBJECT: Radiation Hazard from a Fault at the HTB and Booster Intersection

Summary

The HTB headwall and beam line near the Booster, Section 29, has sufficient shielding to meet the Laboratory design guidelines for a 'high radiation area' designation during operation of the Booster with heavy ions. During operation of the Booster with protons, this area should be designated a 'high hazard radiation area.'

Methods

The following are facts relevant to shield thickness. A side shield wall with a minimum thickness of 5 feet earth is assumed to separate the Booster and Section 29. Going from HTB and toward the Booster, a vertical downward slope of 1 foot per 80 feet length of HTB beam pipe exists. In order to meet with the Booster beam, the HTB beam is pitched level near the Section 29 headwall. Thus, a direct line of site from Booster beam height back through Section 29 and back toward the HEBT section of Linac is eliminated. The thickness of earth between the headwall and Booster is 15 feet. The beam pipes in these areas are 4 inches in diameter. Between the Booster and Section 29, a 10-foot long, 24-inch diameter pipe contains the 4-inch beam pipe (see attached Figure HTB-6.5, Reference 1). This 24-inch pipe reduces to a 5-foot long, 8-inch pipe just prior to penetrating the shield leading toward the Booster Ring.

The following are facts relevant to particle losses. The HTB beam enters the Booster at an angle of 146° with respect to the circulating beam. The operating parameters for sulfur ions, gold ions, and unpolarized protons are taken from the page 28, Booster PSAR (2). In the Linac and when loss of the quadrupole focusing system occurs, the 200 MeV proton beam is assumed to be lost over a distance of 30 feet (3). A longer distance is appropriate for 1.5 GeV protons. For a sulphur ion, individual nucleons in the ion have an energy of 970 MeV. For a gold ion, individual nucleons in the ion have an energy of 350 MeV. For a small area loss in line of sight with the 24-inch pipe sleeve which leads back to Section

1. T. Robinson, Heavy Ion Transfer Line to Booster, HTB, Preliminary Safety Analysis Report, May 8, 1989.

2. AGS and ADD Staff, AGS Booster Project, Preliminary Safety Analysis Report, December 1, 1987.

3. G. W. Wheeler and W. H. Moore, Shielding of the 200-MeV Linac, Brookhaven National Laboratory Report, AGSCD-10, Accelerator Department Internal Report, May 18, 1966.

29, I assume particles are lost over a distance of 30 feet. In order to approximate the dose from a small area loss of beam in the Booster, I assume 7% of the Booster beam is lost at a point in line of sight with the beam pipe leading to Section 29. The Section 29 headwall is 25 feet from a loss point in the Booster which is in direct line of sight. For a small area loss which is lateral to Section 29, I assume a line of particles spread over 30 feet in the Booster. One would not run for significant periods of time in a fault condition.

For high energy particles, the formulae from Tesch (4) are used to calculate dose equivalent at 90° relative to the direction of the protons or heavy ions. Heavy ions are treated as groups of nucleons, and each nucleon is assumed to have an energy equal to the average energy per nucleon. A program, written in Basic, was used for the calculations (see attached). Since individual nucleons in gold ions are less than 1 GeV in energy, the dose estimates from these equations are overestimated. However, the dose estimates from these equations are suitable for protons and sulphur ions at high energies.

For an angle of 146° with respect to a point loss of high energy nucleons, the number of secondary radiations is decreased by a factor of 10 relative to that at 90° (5). This factor of 10 reduction is used to estimate dose from neutrons streaming back through the beam pipe. It is not used for lateral losses.

In a fault in Booster, a sea of low energy neutrons and photons may exist near the fault, and some may leak down through the HTB beam pipe. However, these neutrons and photons will travel many pipe diameters before reaching Section 29 or beyond, and encounter scattering and absorbing surfaces. The dose from this low energy component is estimated to be less than the dose from the high energy particles streaming down the pipe, and is ignored. At locations other than inside of a beam pipe, the existing shielding will completely remove low energy neutrons and photons which originate near a fault in the Booster.

The fault level of dose equivalent at the HTB beam pipe at the Linac headwall is calculated by assuming a 4-inch radius isotropic source of neutrons at the Section 29 headwall. It is assumed to be at a point near the pitching magnet. Scattered neutrons are assumed to travel down 90 feet the beam pipe and exit at the HTB/Linac headwall. A reduction of 70,000 is calculated for neutrons from this source.

Results

Part-time or full-time occupancy at the surface of the HTB/Linac or Section 29 headwalls is not assumed. Because of possible fault levels greater than 100 mrem in 1 hour, Section 29 should be considered a potential 'high radiation area' during heavy ion running, and should conform with the specifications in the BNL Occupational Health and Safety Manual which are listed for an area of this type. During proton running in the Booster, Section 29 should be regarded as a 'high hazard radiation area'. During proton running in the Booster, the HTB/Linac headwall should be considered a 'radiation area'. Fault studies should be performed in order to verify if these designations are appropriate.

---

4. K. Tesch, "Comments on the Transverse Shielding of Proton Accelerators," Health Physics, 44, pp. 79-82, 1983.

5. K. Tesch, "A Simple Estimation of the Lateral Shielding for Proton Accelerators in the Energy Range 50 to 1000 MeV," Radiation Protection Dosimetry, V11, pp.165-172, 1985.

The dose equivalent rates are:

Small area fault at end of HTB beam pipe in Booster

Location in HTB Line	Fault Dose Equivalent Rate, rem in 1 hour protons	sulfur ions	gold ions
4-inch beam pipe at Section 29 headwall	20	0.09	0.04
4-inch beam pipe at HTB/Linac headwall	$3x10^{-4}$	$9x10^{-7}$	$5x10^{-7}$

Small area fault at Booster at a lateral location to Section 29

Location in HTB Line	Fault Dose Equivalent Rate, rem in 1 hour protons	sulfur ions	gold ions
Section 29 near headwall	700	3	2
4-inch beam pipe at HTB/Linac headwall	0.01	$4x10^{-5}$	$3x10^{-5}$

Dose estimates are rounded to 1 significant figure. Normal distributed losses in the Booster Ring are 3,000 times less than the small-area fault condition for proton running.

A full fault in Linac with 200 MeV protons yields an estimated 3 rem in one hour through the minimum parts of the Linac-Booster interface. This is a location which is outside the Linac and on the earth berm. Other nearby Booster areas have greater shielding. In the past year, interlocked Chipmunk radiation monitors set at 2 mrem per hour have been in place at this interface. Losses in this area have not tripped the beam off. A similar, appropriate level of protection will be provided for the HTB-Booster interface during continued Booster construction.

Copy to:

J. Glenn
D. Lowenstein
A. McNerney
S. Musolino
N. Rohrig
W. Weng

D. Beavis 1/14/91 DB

SUMMARY OF LINAC FAULT STUDIES 1-3

The objectives of Linac fault studies 1-3 were to measure the adequacy of shielding around several Linac penetrations installed for the Booster, determine levels on the Linac berm, and levels in the AGS tunnel. Levels were within the margin of error of those predicted before the fault study.

Actions taken as a result of these fault studies are:

1. The HTB tunnel section near the Linac has been upgraded to a radiation area.
2. The Booster enclosure and Building 914 have been upgraded to a radiation area.
3. The berm over the Linac has been posted as a radiation area.
4. The area surrounding the entrance gate to the BLIP line pump house has been posted as a radiation area.
5. Additional entrance precautions to the AGS tunnel when the Linac is operating have been implemented.

The above actions should bring these areas into compliance with all AGS/BNL/DOE standards for full intensity Linac beam faults in the transport from NZ86 to the HEBT stops.

Fault Study Intensity

All fault studies were conducted with the same beam intensity. The Linac beam parameters were:

1. 20 mA (25)
2. 100 μs pulse width (500)
3. 3 second repetition rate (0.2)

The maximum for each of these parameters is given in parenthesis. These fault studies were conducted with 4×10^{12} protons/sec at 200 MeV. The maximum beam intensity is 3.75×10^{14} protons/sec at 200 MeV. All numbers given below have been scaled to the full Linac beam intensity.

HTB Tunnel

The quadrupole NQ134 was used to fault the beam (FSP 3). Levels in the HTB tunnel were:

34 mrem/hr at the sandbags in 2-foot driven pipe
131 mrem/hr at the end of the small transport pipe

The area of the transport pipe is much smaller than 1000 cm^2 and BNL OHSG 3.4.0 allows this to be derated for full body exposure. The reduced dose equivalent rate is well below 100 mrem/hr. Making the section of the tunnel nearest the Linac a radiation area will bring this area into compliance for full Linac beam faults in the transport near the HTB-Linac penetration.

Booster Enclosure

The LTB penetration to Booster was studied by inserting beam stop NZ86 and later the quadrupole NQ68 was detuned (FSP 2). All levels measured were between 9-28 mrem/hr. In addition, a Chipmunk which interlocks at 2 mrem/hr is in this area.

The HTB penetration was studied by detuning NQ134 (FSP 3). Levels along the Booster wall across from Booster dipole C1 were less than 10 mrem/hr. Levels at the sandbags in the pipe were 10 mrem/hr. The end of the beam transport pipe had levels of 80 mrem/hr (average of 3 measurements).

The Booster enclosure and Building 914 were upgraded to a radiation area. In the long term, the Booster enclosure will be a high radiation area and Building 914 a radiation area. This posting will bring the areas near the Linac into compliance for full Linac beam faults.

Linac Berm

Beam was put on the HEBT stops (FSP 1) and the NZ86 stop (FSP 2) to determine the adequacy of the Linac shield. The maximum level measured was 28 mrem/hr with typical levels of 10-15 mrem/hr. The area over the Linac berm was posted as a radiation area. It was previously recognized that full Linac beam on these stops could cause levels of 15 mrem/hr on the berm, and the specification for the Booster fence calls for it to enclose this area in the Booster berm area. The Booster berm barrier will meet Class IV (high radiation area) barrier standards.

The cable pipes into the HTB section of the Linac were examined during fault study 3 and found to have 10 mrem/hr. This area is enclosed in the Linac berm posted area.

BLIP Line Pump House

Measurements were taken at the BLIP line pump house gate with beam on the HEBT stops. Assuming a quality factor of 1 (the HPI 1010 has 5), then the levels at the gate have a maximum level (all beam on HEBT stops) of 19 mrem/hr. A Chipmunk inside the pump room had a quality factor of 1 and was near the demineralizer. It had a maximum reading of 560 mrem/hr for full beam on the HEBT stops. An area outside the gate was posted as a radiation area.

The AGS Tunnel

Levels in the AGS tunnel were measured with Linac beam on the HEBT stops. Levels at three locations were taken and have been corrected for residual background. The locations and levels are (for full Linac beam on HEBT stops):

1. 660 mrem/hr at Linac pipe penetration of AGS ring
2. 800 mrem/hr on wall halfway between Linac pipe and HEBT gate
3. 2800 mrem/hr at the HEBT gate

These levels are within guidelines for a high radiation area but are certainly not desirable. The following has been done to reduce the possibility that personnel could receive inadvertent doses in this area:

1. Linac operations has been instructed to minimize beam on the HEBT stops. Note that typical beam to the HEBT stops is at least 15 times smaller than the full Linac beam.

2. When the ring is on restricted access, a Chipmunk will be placed in this area as a local area monitor.

3. Additional posting to warn personnel that the Linac-to-AGS interface can have high radiation levels.

Whether these actions are sufficient for this running year will be investigated. When the Booster becomes operational, these stops may be moved upstream toward the LTB section.

mvh

copy to:

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TESTS CONDUCTED BY S&EP AND TANDEM PERSONNEL ON 05/16/90

BEAM PARAMETERS

Ion — O-16
Energy — 106 MeV, 6.625 MeV/amu
L.E. Cup — 16 nA DC
H.E. Cup — 50 nA
Obj Cup — 48 nA
11030 Cup — 13 nA (Q= +7)
11060 Cup — 13 nA (Q= +8)

LOCATIONS OF MEASUREMENTS

Pos. 1 — D1 Object Slits @ 2ft -45°
Pos. 2 — D1 Magnet @ 1ft highest radiation level location
Pos. 3 — 11FC060 @ 1ft -15°

METERS

Golf Cart — TVDG Radiation System Monitor with Artificial Background
Snoopy — S&EP R.A.P. Team Snoopy

MEASURED NEUTRON LEVELS

D1 Object Slits - 2x2 mm
- Pos. 1 — Golf Cart — 4 mr/hr - neutrons
- Pos. 1 — Snoopy — 1.2 mr/hr - neutrons
- Pos. 2 — Snoopy — 5 mr/hr - neutrons
- Pos. 3 — Snoopy — 30 mr/hr - neutrons

D1 Object Slits - 3x3 mm
- Pos. 2 — Snoopy — 9 mr/hr - neutrons
- Pos. 2 — Golf Cart — 13 mr/hr - neutrons
- Pos. 3 — Snoopy — 30 mr/hr - neutrons

MEASURED GAMMA LEVELS

Pos. 3 — Worst Case — 1 mr/hr gamma